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GUN MAKING
IN THE UNITED STATES

By

CAPTAIN (NOW COLONEL)

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ORDNANCE DEPARTMENT
U. S. ARMY

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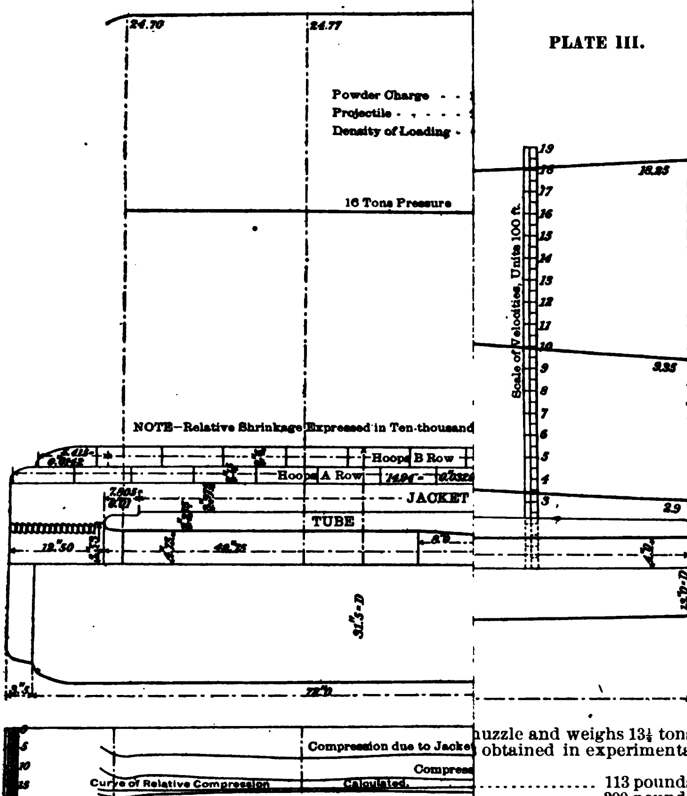

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Diameter of Bore Exaggerated 1000 Times.

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PREFACE.

As a preface to that which follows, it is proper to state that the conclusions and opinions expressed, except when otherwise stated, represent the opinions of the writer and have no official sanction. The subject-matter aims to be a history of the progress of gun making and gun trials in the United States, especially with reference to the part taken therein by the War Department, in the past fifteen years or from the date of the Heavy Gun Board of 1872; and prior to that of such matters as appear to have a bearing on current questions of gun construction. The prominent part taken by the Navy Department in being the pioneer of built-up forged steel guns—thanks to its energetic efforts backed up by liberal and progressive Naval Committees of Congress—deserves the fullest recognition, and if a comparatively brief mention is made of the operations of that Department in general it will be understood as due to the force of circumstances which render even a somewhat detailed account of matters with which the writer is most familiar a matter requiring all the time and attention at his disposal. The data given have been collected from official reports or otherwise, with every regard for correctness. The chronological order adopted for this description of events has led to a much more extended treatise than was at first intended and perhaps also to repetitions which may appear unnecessary; but this order having an advantage in respect to the time necessary to devote to the preparation of the paper has been adhered to.

GUN MAKING IN THE UNITED STATES.[a]

I.

INTRODUCTORY—EARLY INVENTIONS—RODMAN METHOD OF CASTING—SMOOTHBORE GUNS—PARROTT RIFLES.

By CAPT. ROGERS BIRNIE, Jr., U. S. Army, Ordnance Department.

Within the past few years the constituted authorities of both the Army and Navy have, with a marked unanimity of opinion, advocated the construction of built-up steel guns and have entered upon their manufacture to the extent of available appropriations by Congress. Until this time, with the exception of the Ordnance system of converted guns, the art of gun making in the United States made slow progress, compared with the rest of the world, from the time when our Rodman and Dahlgren cast-iron, smoothbore guns reached their best development and gave us a brief period of superiority. That was some twenty-five years past, and the guns we have available for seacoast defense to-day comprise these same smoothbore guns, supplemented only by a limited number of the converted muzzle-loading rifles, which date back to 1872, and are now classed as guns of third-rate power. The same was true of our field artillery; but in this respect much has been accomplished, and work is now in progress that will give us at least a limited supply of the best class of modern light field guns. In small arms, and machine guns firing small ammunition, only has the United States maintained an advanced position.

The reason for this state of affairs is, I think, easy to discern. The trade in munitions of war must, like every other industry, obey the inevitable law of supply and demand. The demand for small arms for general use in our own country, and the fact that the cost of the development of these arms places the matter within reasonable control of private industry and does not necessitate a very considerable expenditure on the part of the Government, has maintained the nec-

[a] Read before Military Service Institution November 26, 1887, Major-General Schofield in the chair.

essary skill in the art and has enabled our private makers to compete successfully in the markets of the world. With guns of a heavier caliber the case is very different. Governments alone need a supply of these, and governments alone can create a demand for them. The close of the civil war found us with an established system of smoothbore, cast-iron guns possessing great merit. But hardly had we time to congratulate ourselves upon this circumstance before the advance of foreign powers in the manufacture of rifled guns forced us to admit our inferiority. We all know the result of the struggle which established the relative merit of smoothbore and rifled guns. We placed implicit confidence in cast iron as a metal for cannon, and so continued for a number of years to use that metal in endeavoring to establish a system of rifled guns, while other nations were coming to discard it more and more in favor of wrought iron and especially steel. Our first rifled guns, introduced in 1861, were made of cast iron, and a limited degree of success was obtained; then others were tried, with signal failure, and the attempt, for the time being at least, fell flat. In Congress the culmination of the matter was reached in the terrific report of the Select Committee on Ordnance, 1869. And in the War Department, in his annual report for 1871, the Chief of Ordnance said: "The results obtained will not warrant me in recommending that any cast-iron rifle guns be procured for arming the forts." All this happened sixteen years since and should have been conclusive, yet there are not wanting manufacturers and laymen to-day who still advocate cast-iron rifles. Judging from the course of legislation since that period, it appears that the country has scarcely yet recovered from the paralysis occasioned by the discovery that our justly vaunted cast-iron gun-metal, which had done such excellent service in the short heavy smoothbores, was not a reliable metal for rifled guns. We have been stumbling along in the rear ever since. The idea that if we were to have guns they should be made with *existing* facilities in the United States, unaccompanied by any whole-hearted effort to improve those facilities, has always been kept to the front. It has retarded our progress and continues to do so. Certainly, I say, the material for guns, and the guns themselves, must be of home production; but why it should be considered of such doubtful policy to encourage improvements in the manufacture of material and guns, and thereby benefit commerce as well, is a position which is difficult to explain. The very conservative course of legislation in Congress in past years has been explained by saying that the rapidly changing developments in guns and armor would enable us, by waiting a few years, to take up the subject at an advanced stage and thus derive the benefit of the vast amount of experimentation continuously being carried on in other countries. Meantime, the policy

has been pursued of maintaining a show of organization for the Service and in testing immature inventions of various designs; and board after board has been appointed with sufficient frequency to keep the matter in apparently well-meant agitation. Finally, a climax has been reached; we are now in a position to know that navies have been established throughout the world which must exist for years to come, and that equally with this the consensus of nations has adopted a system of construction for guns which is capable of overcoming these vessels and is, besides, the strongest and most reliable ever made. In shooting qualities and endurance this system—the built-up steel gun—is to-day without a rival, and as long as these qualities remain essential to a gun it promises to remain equal to the best. These facts have been exploited for several years and gain new confirmation every day. Congress has given no appropriation for the armament of fortifications in two years past, and the apparent reasons for this have been much discussed. The committees have been unable to decide for themselves what measures to adopt. Two important questions were under consideration—first, as to the kind of guns that should be provided, and, second, the propriety of changing the present methods of administration in the procurement of guns. To anyone who has had the privilege of appearing before these committees and hearing the conflicting character of the testimony taken, the wonder is—supposing that equal weight is given to the testimony of individuals, as appears to be the case—the wonder is, I think, not that the committees should remain undecided, but it would be strange that they should reach any conclusion at all. As to the proposed change in the method of administration—taking away from the present organized Bureau of the War Department the control of these affairs and creating another bureau under the same Department or else an independent commission of some sort—that is a matter about which Congress will, no doubt, come to a wise conclusion. It is a question of the substitution of one set of agents for another, or of a multiplication of the paraphernalia of government. It does not seem probable that the laws will be so changed as to substitute a changeable commission of mixed political affiliations for the individual responsibility now held by the head of the War Department, and under him the Chief of Ordnance, assisted, as he is, in the discharge of these duties by a body of officers already trained at the expense of the Government, appointed for life, and subject to removal only through bad behavior. This much we may at least hope—that the question of what guns the Army shall use will remain intrusted to military men.

But the main question before us is as to the type of gun to be adopted. And in this matter, I think, we should make a very clear distinction between an existing established system and experimental

construction. By all means let experimentation go on, only this should not interfere with the production of guns for service when we have at hand the highest type of modern gun, the outcome of years of experimentation, to work upon. The conception of a new design for a gun is a very small part of its successful production; the history of gun making abounds in new designs of form and material, but how few in number have been the successful types. It is a very small matter to perfect a small invention, but to even approach perfection in a heavy gun is one of the most expensive and laborious questions of modern times. So it has been proved the world over, and so it has been shown in such gun trials as have been made in the United States in recent years, wherein an opportunity has been afforded for the test of a number of different systems, to which I will refer.

In reviewing as briefly as may be the history of gun making in the United States in order to trace its effect upon questions of the day, it will be necessary to begin a connected account with the period of Rodman's improvements in making cast-iron smoothbores. From that period up to the present era of steel guns we will follow the chronological order of the trials made under the supervision of the War Department.

Some of the earlier designs of guns possess an interest, because of the successful application of the principles involved in guns now in use. Of such were those, dating from 1841, made after the plans of Daniel Treadwell.[a] Professor Treadwell's first gun was made of rings or short hollow cylinders of wrought iron joined together end to end by welding. Each ring was made of several thinner rings, placed one over or around the other and welded. Subsequently the method of making the rings was somewhat changed by first making a single ring of steel about one-third the thickness of the whole and upon the outside of this winding a bar of iron spirally, as a ribbon is wound upon a block. Machinery was devised for making the rings, welding them together, and forming the guns by means of various molds, dies, and sets connected with a powerful hydrostatic press. The breech was closed with a screw plug, and a trunnion band formed by the machinery was screwed upon the outside of the gun. The object of this method of manufacture was to so dispose the metal as to place the direction of the fiber in opposition to tangential rupture.

Professor Treadwell's admirably conceived idea was to make a gun of equal strength in all directions. He demonstrated the proposition that, proportioned to the arena of resisting metal, the tendency to tangential rupture would be several times greater than the ten-

[a] A short account of an improved cannon, and of the machinery and processes employed in its manufacture, by Daniel Treadwell, Cambridge, 1845.

dency to transverse rupture; hence he arranged the metal to oppose its lines of greatest strength to the effort of the tangential strains, and thus economized his material and approached, as nearly as could be with the means employed, the conception of his ideal gun of equal resistance. These guns were tested both by the Army and Navy. The smaller calibers stood well, and the Ordnance Board in 1846 recommended batteries of 6 and 12 pounders and 12 and 24 pounder howitzers, approved by the Secretary of War in 1847. Subsequently it appears some guns of larger caliber—32 pounders—supplied to the Navy did not prove successful. We can not find in this method of construction more than a very remote resemblance to the principles of the modern built-up gun, but its development was directly shown in the after success of the coil system of wrought-iron gun construction, illustrated in the Armstrong and Woolwich guns of the period 1856 to about 1880, the breech bands of the Parrott guns, and the coiled welded tubes of our converted guns.

The early development of the modern system of hooped guns is traced through General Frederix, in Belgium, in 1830; Thiery in France, whose first gun was constructed in 1833; Chambers' American patent for a hooped wrought-iron gun, dated July 31, 1849, and the English and American designers, Blakely and Treadwell, in 1855. Between these two last there exists a question as to priority of the principle of initial tension in hooped guns, or of giving to the several layers of hoops such a shrinkage as would cause each to offer its full strength in resisting the action of an interior pressure calculated to rupture the gun. But we are most indebted, I believe, to the investigations of Lamè and Barlow for the origin of this principle and to Rodman's exposition of it, precedent to his endeavor to apply it in a cast gun. Chambers' patent of 1849 is especially worthy of note, in that it embodies—

First. The slotted screw breech fermeture.

Second. The hinged movement of the breech mechanism, when withdrawn to clear the way for loading through the breech.

Third. The loading tray or sleeve inserted in the breech to cover the threads in loading.

Fourth. The biconical shape given to the shrinkage surfaces of the hoops to afford longitudinal strength.

In design this gun was a wrought-iron breech-loading smoothbore, built up with a tube extending in one piece from breech to muzzle, and incased with several layers of hoops, shrunk on. The principle of initial tension is not enunciated in the design, but it was provided that the rings should be put on at a heat sufficiently low to prevent oxidation. We find the slotted screw, the hinge movement of the breech mechanism, and the loading tray in the perfected system now designated the French breech mechanism. The biconical shape of

hoops is an idea not long since introduced in the De Bange guns, but its utility is doubtful. As regards the Broadwell ring used in the Krupp gun, it appears to have been derived from a patent taken out by Broadwell in Russia. Broadwell's patent was placed first in Russia in 1861, second in England in 1864, and third in the United States in 1866.

INITIAL TENSION IN CAST-IRON GUNS.

The great improvement in the manufacture of cast-iron smoothbore guns was due to the introduction of Rodman's method of casting, by cooling from the interior, coupled with the well-conditioned outside lines which he adopted for his gun. Major Wade's report of August 4, 1849, contains an account of the trial of the first gun made on this plan. Two 8-inch Columbiads were cast at the same time from the same metal. One was cast solid in the usual manner and the other according to the Rodman plan. The first was burst at the eighty-fifth round, while the second endured 251 rounds. An equal and even greater degree of superiority was evinced in the succeeding trials of 8 and 10 inch guns made in 1851. The object sought to be attained by Rodman finds application to-day in what we consider the highest principles of gun construction. Following the discussion of the action of a central force as enunciated by Barlow some years previously, Rodman, in 1851, pointed out not only the injurious effect of exterior cooling as causing a zone of metal near the exterior to remain in a state of compression and thus actually assist in the rupture of the gun, but also showed that the effect of cooling from the interior would be to so dispose the metal that in resisting an interior pressure each concentric laminæ of metal throughout the wall might be equally strained to its limit to resist tangential rupture. To use his own words, referring to a gun which had withstood 1,500 rounds without bursting: "The object of my improvement was in part, if not fully, attained, viz, to throw the gun upon a strain such that * * * each one of the indefinitely thin cylinders composing the thickness of the gun shall be brought to the breaking strain *at the same instant.*" Evidently a condition like this would give a maximum resistance, since it would be determined by the product of the mean strain of the laminæ into the thickness of the wall, and if each laminæ worked to its limit that product would be the greatest possible.

But while we may not deny the utility of the Rodman process as a whole, it was, and must continue to be, uncertain in its operation, independent of the always existing uncertainty about the soundness of the castings. A number of cases are known in which the castings burst spontaneously on cooling, and in some cases after being put in the lathe for finishing. And we know also that a frequent cause for rejec-

tion of these guns was the existence of cavities uncovered in the boring. The plan may be expected to do more than counteract the effect of the hurtful strains arising from cooling solid castings in the usual manner; it will, in fact, produce to an uncertain extent, however, the proper direction of initial strains. It would be the merest accident should there be brought about the perfect state indicated by the theory. Nor was this to be expected, since the question of the proper degree of temperature to be maintained at the exterior and the rate of cooling from the interior was investigated only in a crude manner. A little study of the problem will show that in order to produce an accurate degree of tension in the indefinitely thin cylinders composing the thickness of the wall the most delicate appliances would be necessary; the exterior should remain heated to the very last and the cooling progress regularly, according to a certain fixed law, from the interior. Again, it is impossible to maintain the heat of fusion at the exterior sufficiently long for this process to be accomplished, so that the metal there becomes set and prevents a zone of adjacent metal within from contracting as it should upon the interior mass. These are not theoretical ideas; they are the results of careful investigations. The method adopted for determining the amount of tension in the castings was to cut off a thin cross section of the gun to form the "initial tension" ring, and then slot this ring through on one side along a radius, the separation of the ring measured in the slot at the outer circumference being taken as a measure of the tension. To what extent this method gives a true measure of the initial tension strains is entirely problematical and unknown; it can be said only to show the aggregate result of the interior strains of every sort existing in the castings, and either localized or general. In theory, it was desired to reach an initial tension of about 20,000 pounds, or two-thirds (66 per cent) of the average resistance of the cast iron. In practice, however, it was found that the initial tension of the 10-inch guns varied from 3,000 to 28,000, or from 12 to 72 per cent of the actual tenacity of the iron, and the 15-inch guns from 4,000 to 25,000, or from 15 to 61 per cent of the actual tenacity. These results combine two equally important and unknown factors, viz, the uncertainty of the method to produce the results desired, and the inadequacy of the method used for determining the initial tension. Investigations and extended attempts to introduce the Rodman method of casting have been made in Russia and proved unsatisfactory, because it was found, upon careful investigation, that the desired state of initial tension could not be produced with any degree of certainty.[a]

The results of an important investigation recently made at Watertown Arsenal in this matter are given in Notes on the Construction of

[a] Notes on the Construction of Ordnance, No. 21, p. 7.

Ordnance No. 38, by Lieut. William Crozier, Ordnance Department, U. S. Army. "To determine the form of the initial tension curve and the value of its ordinates, a ring (section) was cut from the portion of the sinking head of the gun immediately adjoining that from which the trial cylinder was taken. This ring was scored with concentric circles about 1 inch apart, whose diameters were measured. It was then finshed to the radial dimensions of the trial cylinder and the diameters of the circles again measured. In this state it had the initial condition of the trial cylinder.[a] It was then cut into concentric rings, a little less than 1 inch in thickness, by cutting midway between the scored circles, after which the diameters of the circles were a third time measured—the changes of dimensions indicating the amount and character of the strains to which the small rings were subjected before being detached. The dimensions were measured with great care on four different diameters, making equal angles with each other."

The results of the measurements thus made are shown in the following figures:

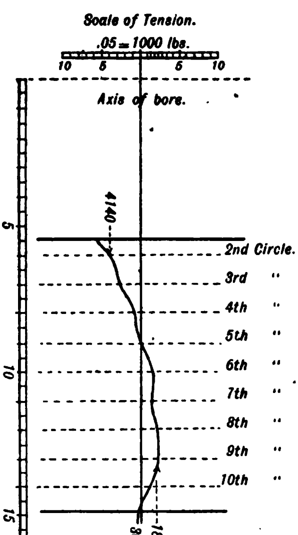


Fig. 3. Initial state of trial cylinder.

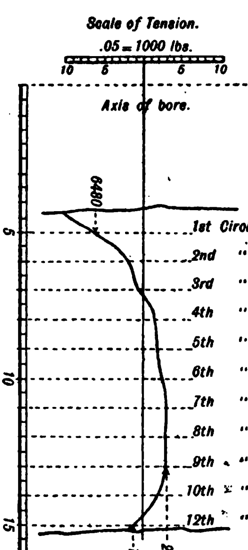


Fig. 2. Initial state of rough casting.

The expansion of the thin rings on being released gave a measure of the compression to which each had been subjected in the casting, and the contraction of others showed their state of extension in the casting. The platted curves show that the interior of the casting was compressed as designed in the Rodman process, but the exterior was in a state of irregular tension. The highest state of extension is

[a] Referring to the core of an experimental wire-wound gun cylinder.

about one-fifth the thickness from the exterior, and the exterior metal itself was in a state of compression—thus producing a strain in that place which would tend to assist an interior (powder) pressure in bursting the gun. This method of investigation is evidently best suited to elucidate the efficacy of the so-called "natural hooping" involved in the Rodman process. The detached rings were made as thin as could be manipulated with due regard to accuracy of results, and a good degree of approximation was made to separating the section into the indefinitely thin cylinders of which the wall is conceived to be composed. The action of these thin cylinders, on being detached from the section, indicated their state of strain in the casting and gave a measure of the efficacy of the natural hooping—it being considered that the rings became practically neutral, regarding tangential strains, on being detached. At a subsequent period these thin rings were cut in two on one side in a similar manner to the ordinary test of an initial tension ring or full section of a gun. Their behavior was very irregular, and gave no indication of the initial tension shown by the preceding experiment to have existed in the wall of the casting. This behavior of the thin rings, on being cut apart, indicated the existence of local strains of an uncertain character, and showed the unreliability of the initial tension test as usually followed. I have devoted the more space to this subject of initial tension than might otherwise be considered necessary, because of its bearing upon the question of steel-cast or other guns now advocated to be made after this process.

CAST-IRON SMOOTHBORE GUNS IN SERVICE.

The number of Rodman smoothbore guns now available for the land service is 210 8-inch, 998 10-inch, 305 15-inch, and 2 20-inch. These guns, if properly mounted, can be expected to perform efficient service in case of necessity. For armor piercing, the 8 and 10 inch would be of little value. The powder charge of the 10-inch is 25 pounds of mammoth powder and the round projectile weighs 128 pounds, giving a muzzle energy of 2,000 foot-tons, which, however, for this form of projectile, would fall away very rapidly. But these guns may be made useful in the defense of minor points and torpedo lines. The 15-inch gun fires a projectile weighing 450 pounds, and through the experiments made by the Ordnance Board at Sandy Hook in 1883 its powder charge has been increased to 130 pounds of hexagonal powder, which gives an average pressure of about 25,000 pounds per square inch in the bore. With this charge the range at 20° elevation is 3.75 miles. At the same time it was found that the projectile would pierce 10 inches of iron at 1,000 yards. The initial velocity of 1,700 f. s. imparts a muzzle energy of 9,000 foot-tons, but so rapidly would

this fall off that at 1,000 yards the energy would be considerably less than that of the projectile of the new 8-inch steel rifle, which starts with an energy of 7,200 foot-tons.

PARROTT RIFLES.

Although all the Parrott guns are now classed as "retained calibers" in the service—that is, only to be used in cases of necessity—they performed a most important duty in our civil war, and are especially worthy of mention as being the first extended system of rifled guns introduced in the United States. Their founder and maker will always be regarded as one of our most successful gun makers, and remembered as a man distinguished in the art. He made a wide reputation for himself and for the West Point Foundry, at Cold Spring, N. Y., which, under his successors, has continued to afford indispensable aid to the Government in the production of new types of guns, and has materially assisted in maintaining and diffusing a knowledge of gun making in the country. My personal obligations in this respect are deep, for it has been my good fortune to have remained on duty there as an inspector for nearly six years, with opportunities for acquiring the practical knowledge that abounds at the foundry.

The history of the Parrott guns is so well known that it will be necessary to call attention only to certain features. The smaller calibers showed in some cases a remarkable endurance in war service, and the same was true to a less extent with the larger calibers, but failures of the 100, 200, and 300 pounders were relatively numerous. Several instances which have occurred in practice firing with these guns in recent years have also, in connection with modern improvements in construction, led to the obvious necessity of retiring them from service as soon as they can be replaced. The uncertainty in endurance of the heavier calibers must be regarded as evidence of the unsuitability of cast-iron as a metal for making heavy rifled guns. Any system of conversion for these guns would necessitate an enlargement of the bore, and corresponding thinning down of the already weak walls; moreover, the guns were made for quick burning powder and are too short to realize a proper effect with slower burning powders. The wrought iron reenforce band of these guns was made from a bar coiled and welded in the form of a hollow cylinder, which was afterwards finished for shrinkage. The effect of this was to dispose the fibers of the iron to resist tangential rupture, and the band was probably not expected to afford any resistance to longitudinal rupture. The cast-iron wall of the 100-pound rifle, for instance, is one caliber (nearly) in thickness, and the thickness of the reenforce band is one-half caliber (3.2 inches). The shrinkage prescribed for the band was one-

sixteenth of an inch to the foot, or 0.0052 of an inch per linear inch. This is fully four times as much as would now be regarded a useful limit for the shrinkage of a wrought-iron gun hoop; however, these bands were assembled at a high heat and the iron band was allowed to adjust itself without exterior cooling; hence we do not find in these guns an example of the practice of hooping, as now understood. And the excessive shrinkage of the single band, by producing unduly heavy cross strains in the section of the cast-iron at the front, tends to weaken the gun to resist longitudinal rupture, as may be inferred from the manner in which a good proportion of the failures have taken place.

II.

Period from 1872 to 1881—Hitchcock, Mann, Lyman-Haskell, and Woodbridge Guns—Converted Muzzle-Loading Rifles—Converted Breech-Loading Rifles—Sutcliffe and Thompson Guns—Field Guns.

The Heavy Gun Board of 1872 was appointed to meet in New York City for the purpose of examining such models of heavy ordnance as might be presented to it, and of designating and reporting to the Chief of Ordnance such models as might be selected for experiment. Colonel Whitely, of the Ordnance Department, was president of the board, and there were besides one officer of Engineers, two of Ordnance, and two of Artillery as members. A special appropriation was made in advance by Congress for the purpose of carrying out the recommendations of the board. The board examined into 40 inventions and proposals, and selected the 9 following, arranged in the order of merit determined by the board, viz:

Muzzle-loading guns:

1. Dr. W. E. Woodbridge.
2. Alonzo Hitchcock's.
3. Cast-iron guns, lined with wrought-iron or steel tubes.

Breech-loading guns:

1. Friedrich Krupp.
2. E. A. Sutcliffe.
3. Nathan Thompson.
4. French and Swedish system.

Miscellaneous:

1. H. F. Mann's.
2. Lyman's multicharge.

The Ordnance Department was occupied in the ten years following, pursuant to enactments of Congress, in the construction and trial of the guns recommended by this board. The Krupp gun was intended to be tested for a trial of the breech mechanism as well as the system of construction. However, no gun of Krupp's system was procured, for the reason the War Department was unable to comply with his conditions, which necessitated the purchase of a number of guns in case the trial gun should prove a success. Such an agreement by the War Department could only have been made

in case Congress had already appropriated the money for the purpose, and this was not done. But the Krupp breech mechanism was subsequently tried in combination with the converted wrought-iron lined guns recommended by the board, after the muzzle-loading guns of the same type had been successfully tested.

The Hitchcock gun proposed was a 9-inch muzzle-loading rifle, to be made by welding together disks or "cheeses" of wrought iron forming sections of the gun to make a solid wrought-iron piece. The work was conducted at the Springfield Armory under the direct supervision of the inventor. After nearly three years' labor and the expenditure of a large amount of money the project was abandoned as being too difficult and costly, if not impracticable, to be fulfilled.

No provision was made in this period for a trial of the French and Swedish system. The Mann gun considered by the board was an 8-inch breech-loading rifle, already in possession of the Ordnance Department, which had already been fired about 50 rounds. Some alterations were made, and the gun was fired 11 rounds at Sandy Hook in 1875, after which it was moved to Philadelphia to be placed on exhibition at the Centennial. The Lyman's multicharge gun in existence at this time was a 6-inch breech-loading rifle, designated by its private owners as the "Multicharge 100-pounder rifle gun." But since improved models of both the Mann and Lyman-Haskell guns were tested at a period subsequent to this, further references will be deferred to an account of those trials.

WOODBRIDGE 10-INCH WIRE-WOUND GUN.

It appears from the record that Doctor Woodbridge first presented a plan for a wire-wound gun to the War Department July 30, 1850, which establishes his claim to priority in the idea. A 2.5-inch gun, constructed upon his plans at the Washington Navy-Yard, was tested for endurance at the Springfield Armory, where, in 1865, Major Laidley reported that 1,327 rounds had been fired from it and the firing had been stopped because the trunnion band broke loose, but the gun itself was practically uninjured. The trial gun decided upon in 1872 was a muzzle-loading rifle of 10-inch caliber. It consisted of a thin steel tube strengthened by wire wound on its exterior surface, tube and wire being subsequently consolidated into one mass by a brazing solder melted into the interstices. The tube extended through from breech to muzzle, was left solid for a length of 19 inches to form the breech, and had a thickness of 1.5 inches around the bore. The length of the bore was 155 inches, or 15.5 calibers. The following brief description of the process of

manufacture is taken from report of Captain Prince, dated March 31, 1875:

Square wire is wound upon a steel core somewhat larger than the intended bore of the gun, a sufficient number of wires being wound at once, side by side, to produce the required obliquity of the turns. The successive layers have opposite twist, their number being, of course, sufficient to give the desired exterior diameter to the gun. When thus wound, the whole mass is inclosed in a tight case, to protect it from oxidation, and is heated therein to a temperature somewhat above that required for the fusion of the metal to be used for consolidating it. The soldering metal is then run in, filling all the interstices of the mass. When properly cooled, the gun is bored and finished from the mass in much the same way as if it were a common casting.

The construction of the gun was undertaken at Frankford Arsenal in October, 1872, and after many delays and difficulties was completed in April, 1876. It was fired 10 rounds at Frankford Arsenal with powder charges increasing from 40 to 70 pounds, and projectiles from 343 to 397 pounds. In these firings imperfect brazing was developed and a crack was started on the exterior of the gun. The same gun was taken up in 1881 and fired for endurance under the supervision of the board on heavy ordnance and projectiles. The charge principally used was 70 pounds hexagonal powder and 395-pound projectile. With a charge of 80 pounds of powder the gun parted longitudinally after a total of 93 rounds, the "fracture being 26.75 inches from bottom of bore in the plane of openings noted and measured during the firing." Notwithstanding the poor success of this gun, as shown in the difficulties attending its manufacture, and its subsequent failure under proof, the Getty Board, being much impressed with the utility of continued experiments with wire guns, recommended that a breech-loading gun of the same construction be made and tried, with others of different designs presented by Doctor Woodbridge. These later designs apparently possess more merit and have superseded the first construction in which the brazing of the wire formed almost the sole reliance for longitudinal strength. The recommendation to try another brazed wire gun has never been carried out.

CONVERTED MUZZLE-LOADING RIFLES.

These guns consist essentially of a cast-iron body or casing, strengthened with a wrought-iron or steel rifled tube which has a thickness of wall, over the seat of charge, equal to about one-third the caliber of the gun. They constitute a system of built-up guns, in which the shrinkage of the casing on the tube is negative, or there is a play. The casing, except in a single gun of new construction—the 12¼-inch rifle—is formed of the Rodman smoothbore gun, from which about fifteen one-hundredths of the caliber only in thickness of cast iron is removed to enlarge the bore for the reception of the com-

paratively thick tube of reduced bore. In the wrought-iron tubes formed by coiling and welding bars of the very best grade of wrought iron, the fiber is arranged to resist directly the dangerous tangential strain, and these tubes are, besides, reenforced over the seat of the charge by a sleeve or jacket of wrought iron, similarly formed and shrunk over. These wrought-iron tubes would alone support an interior pressure of 13,000 pounds per square inch, or more than one-third of the whole pressure that the guns are called upon to bear. Even supposing the tube inert, its interposition causes a reduction of about 31 per cent of the pressure in the bore in transmission to the cast iron, because the pressure upon 1 square inch of the bore would be distributed upon 1.7 square inches of the interior of the outside cast-iron body. In the later constructions where steel is used, the metal is a fine quality of highly ductile steel suited to the construction, and the tube in itself is able to safely support an interior pressure of 18,000 pounds per square inch, or about one-half of the whole strain upon the gun when fired.

In mode of conversion, these guns are divided into three classes, viz: (1) The muzzle insertion with wrought-iron tube; (2) the breech insertion with wrought-iron tube; (3) the muzzle insertion with steel tube.

The difference between the plans of muzzle and breech insertion lies principally in this: In the former the tube is supported longitudinally from a force that would tend to open coil welds by the muzzle screw collar; while in the latter, there are several shoulders on the outside of the tube which bear against corresponding shoulders in the casing, and the tube by this means is well supported longitudinally from movement forward at several distances throughout its length. A special importance attaches to this in the use of coil-welded tubes, which are more apt to develop a weakness at the coil-weld joints than in any other part.

These guns were proposed as an expedient for converting the comparatively useless 10-inch smoothbores into rifled guns to meet the increasing thickness of armor carried by vessels. When this system was inaugurated the 8-inch caliber was seen to be a gun that would equal in power the existing English guns of like caliber, and it was hoped that the extension of the system to guns of larger caliber, would prove a success. As an additional reason for the adoption of the system, our forts were, *and still remain*, constructed with casemates adapted to accommodate a gun of about the dimensions of the 10-inch Rodman, and the conversion of this gun into a rifle afforded at that time, the best and the only available means for increasing the efficiency of the casemated forts to a maximum. At the same time, however, the Chief of Ordnance, General Benét, then

placed himself upon record as saying:[a] "There is little doubt that steel is the best material for guns." He did not recommend an expenditure of a large amount of money for a gun plant to make the proposed conversion, but drew attention to the success of the tubing, as enabling the smoothbore guns to be made strong enough for use as rifles and recommended the system as an "easy and economical mode of converting our cheap cast-iron smoothbores into powerful and efficient rifles."

The lining of a cast-iron body with a steel tube, as a system of construction for rifled guns (10-inch and 12-inch), was recommended for trial by the Ordnance Board, convened under the order of the War Department, dated December 16, 1867. The matter was brought to the attention of the board of 1872 by Major Crispin, and this board recommended the conversion of four 10-inch Rodman guns upon the plans proposed, which were modeled upon the Palliser plan of muzzle insertion, then successfully established in England, and the Parsons (American) plan of breech insertion. The details of the construction of the guns were subsequently arranged by boards of ordnance officers, convened September 18, 1872, and October 10, 1874. It was decided that two of the four experimental guns be made of 8-inch caliber and two of 9-inch caliber, one of each to be tubed from the front, and one from the rear; the muzzle insertion to be wrought-iron tubes and the breech insertions jacketed steel tubes.

The wrought-iron tubes were procured from Armstrong and the parts of the steel tubes from the Bochum Steel Company, Germany. The 8-inch gun, with wrought-iron tube inserted from the muzzle, was at once established as a success. The 9-inch gun, of the same model, was also successfully proved by firing 502 rounds, but this caliber made the gun too light to compete successfully with foreign guns of like caliber. The 8-inch gun, with steel-jacketed tube inserted from the rear, was burst after firing 456 rounds, of which 286 were fired after the development of a crack in the steel tube at the one hundred and seventy-fifth round. The 9-inch gun, of the same model, was not fired to extremity. The steel procured for these tubes was not of the uniform strength considered desirable, and its elastic limit was what we would now consider exceedingly low—that was from 23,000 to 25,000 pounds per square inch. Following the success of the 8-inch muzzle insertion, with wrought-iron tube a gun of 10-inch caliber, converted from a 13-inch smoothbore, and also a new construction—the 12.25-inch rifle—were made upon the muzzle-insertion plan. The 12.25 inch was made 18.5 calibers in length of bore and was, when made, one of the most powerful guns of that caliber in existence. The trials of these guns of larger caliber developed the unsuitability of the muzzle-insertion plan when applied to

[a] Report of the Chief of Ordnance, 1875, p. 94.

them, owing to defects developed in the coiled welded tubes which, in this plan of conversion, received longitudinal support only from the muzzle screw collar. In the proof of the 10-inch gun the tube was torn apart longitudinally, after a few rounds, and a large portion of the muzzle end of the tube was projected forward out of the gun. The tube was repaired, and the gun afterwards fired some thirty rounds. This led to the substitution of the breech-insertion plan as essential to the construction of guns of larger caliber than 8 inches. And by analogy the same reasoning led to the relinquishment of the muzzle insertion for 8-inch guns. Experimental guns of 8 and 11 inch caliber were made on the breech-insertion plan and proved for endurance. Only a few of the 11 inch were made, as this construction gave place to the 11-inch converted breech-loaders. Thus it came about that the 8-inch gun was the only caliber of these converted muzzle-loading rifles which was adopted and manufactured for issue in service.

The wrought-iron tubes for the first two experimental guns were, as already mentioned, procured from England, but the third was procured from West Point Foundry, and the manufacture of these tubes became, at a later period, a regular product of home production. So also with the bar iron for making the tubes. The demand for this production at home soon led to its procurement in the quantity desired and in quality fully equal to foreign make. This iron was manufactured at the Ulster Iron Works, Saugerties, N. Y. The work of conversion was done at the West Point and South Boston foundries.

The use of a steel tube, muzzle insertion, was introduced in the 50 guns last converted. At this time (1883) it had become apparent not only that steel was the best material for guns, but also that improvements in the manufacture of gun steel in other countries had removed the doubts raised by our own trials of inferior metal. It therefore became a highly important matter to encourage the production of gun steel at home. It was found also that the steel-tube conversion could be made at a considerably less cost than the wrought iron. With these ends in view, an experimental gun was first made and satisfactorily proved for endurance. The order for 50 tubes was then placed with the Midvale Steel Works and successfully filled. This was the largest order for steel forgings that had up to that time been placed in the United States. A special fine quality of steel was demanded, possessing great ductibility, combined with a relatively low elasticity and tenacity, and the fulfillment of the order did much to advance the manufacture of gun steel in this country, and as well to increase the experience of the Midvale Steel Company and to establish the excellent reputation for the manufacture of gun steel which that company now holds.

Five hundred rounds was fixed as the number necessary to prove the endurance of the 8-inch guns. The following table gives a list of the type or experimental guns fired and the number of rounds fired from each:

Endurance of experimental converted muzzle-loading rifles, dating from 1874.

	Nature of gun.	Average weight of charge.	Average weight of projectile.	Number of rounds endured.	Condition at end of trials.
	Type guns.	*Pounds.*	*Pounds.*		
8-inch ..	Muzzle insertion, wrought-iron tube (English).	35	180	817	Serviceable.
8-inch ..	Muzzle insertion, wrought-iron tube (West Point Foundry).	35	180	651	Do.
8-inch ..	Breech insertion wrought-iron-tube (West Point Foundry).	35	180	783	Do.
8-inch ..	Muzzle insertion, steel tube (Midvale).	35	180	606	Do.
	Experimental guns.				
8-inch ..	Breech insertion, steel tube (Bochum).	35	180	456	Steel tube cracked at one hundred and seventy-fifth round and gun destroyed at four hundred and fifty-sixth round.
8-inch ..	Chambered; breech insertion, wrought-iron tube (West Point Foundry).	55	180	108	Serviceable.
9-inch ..	Muzzle insertion, wrought-iron tube (English).	40 45	200 230	502	Do.
9-inch ..	Breech insertion, steel tube (Bochum).	40	230	118	Do.
10-inch .	Muzzle insertion, wrought-iron tube (English),	75	400	33	Serviceable, with repaired tube. The original tube was ruptured longitudinally early in the proof.
11-inch .	Breech insertion, wrought-iron tube (West Point Foundry).	90	525	401	Passed prescribed endurance test of 400 rounds. Defects developed in coil welds.
11-inch .	Chambered; breech insertion, wrought-iron tube (West Point Foundry).	125	550	138	Serviceable.
12 to 25 inch.	New construction, muzzle insertion, wrought-iron tube (West Point Foundry).	[a] 150	700	76	Do.

[a] One round with 200-pound charge of powder. The greater number with 100-pound charge.

The 8-inch service rifle of this class is 14.7 calibers in length of bore. The charge is 35 pounds of hexagonal powder, and the projectile weighs 180 pounds. The results of the latest trials with this charge give an average pressure in the bore of 30,500 pounds per square inch, and an initial velocity of 1,385 f. s. From trials made at Sandy Hook in 1883, using chilled-iron projectiles, it was shown that the power of the gun was sufficient to more than penetrate 8 inches of iron armor at 1,000 yards, thus making it an effective weapon to defend narrow channels against the passage of vessels carrying about 8 inches of iron or less.

CONVERTED BREECH-LOADING RIFLES.

The recommendation of the board of 1872 to test the Krupp system was carried out in regard to the breech mechanism by its adaptation to the converted breech-loading guns which were tried, following the success obtained with the muzzle-loading rifles. In general features of the tube construction the breech-loading gun was made like the breech-insertion muzzle-loader. But the jacket was made of a heavy steel piece, which projected to the rear to receive the Krupp fermeture, and this jacket, being larger than the wrought-iron jacket used in the muzzle-loader, considerably more of the thickness of cast iron about the breech was removed, leaving a thinner casing of cast iron. To compensate for this, and to add strength to the breech, a steel hoop was shrunk upon the breech end of the truncated casing; and, in addition to the screw thread used to secure the tube in place, the casing in this construction was also shrunk upon the tube over the length of its jacket. The first 8-inch gun was made and tried. The steel used in this gun was furnished by Whitworth, and was of good quality. The proof of this gun was entirely successful; it withstood 636 rounds, using the same charge as the muzzle-loading rifle without injury, and remained in serviceable condition. Other guns of 8 and 11 inch caliber were then ordered.[a]

The orders given for the manufacture of the converted 8 and 11 inch guns were suspended and canceled when the second trial gun of 8-inch caliber and the first of 11-inch caliber failed under the proof to which they were subjected. These guns differed from the first experimental breech-loading gun in being chambered to receive increased charges of powder—the increase being for 8-inch, 55 pounds instead of 35, and for 11-inch, 130 pounds instead of 90. One 8-inch and the 11-inch gun failed after a few proof rounds, by a clear fracture of the steel breech piece in a plane through the front angles of the slot for breechblock. It is important to remark that in these guns the angles at the front corners of the slot were cut square—a feature which is stated to have caused several of the few recorded dis-

[a] An experimental 12-inch breech-loading chambered howitzer to be converted from a 15-inch smoothbore, and four 12-inch breech-loading chambered rifles of new construction, but of the same general design as the converted 8-inch breechloader, were also projected, and their construction was begun in 1880. The 12-inch rifle was designed for 24 calibers length of bore, with a total weight of about 50 tons, and use 200 to 300 pounds of powder with 800-pound projectile. None of these guns, however, were completed. It became necessary to abandon the construction, because steel of the requisite qualities could not be supplied. The steel forgings for these guns were procured in England, and brought to this country by the contractors, but when submitted for the inspection of the officers of the Ordnance Department, the metal was found to be wholly unsuitable, being materially below the standard guaranteed, and, consequently, the forgings were rejected.

astrous failures in guns made by Krupp. Added to this, the tests of the steel which ruptured in these guns showed a quality of metal badly adapted to gun construction. Four specimens taken longitudinally from the metal of the 8-inch piece gave an ultimate tenacity varying from 79,000 to 112,000 pounds per square inch, and this irregularity of strength was accompanied by an exceedingly low ultimate extension, in one specimen as low as 4 per cent, and not exceeding 9 per cent in the best of the four.

The 11-inch piece showed a much poorer quality of steel, though of an entirely different nature. The average tenacity was uniform, but low, ranging, for 12 specimens, about 66,000 pounds per square inch. The elastic limit ranged between the low figures of 10,000 and 24,000 pounds per square inch, and the metal was soft and friable in its nature. Analysis showed that it contained 0.247 of 1 per cent of sulphur. Subsequently a second 8-inch gun, made at the same time with that just described, was prepared for trial by rounding the front corners of the slot. This gun gave an excellent record in its proof for endurance. It was burst into many fragments at the one hundred and twenty-seventh round, but for 6 rounds preceding that catastrophe had endured a 55-pound charge of powder that gave an *average* of 51,000 pounds pressure per square inch in the bore, and for 15 rounds preceding the 6 named, an equal charge of somewhat slower powder, that gave an *average* of 43,600 pounds pressure.

It was equally unfortunate for the Krupp breech mechanism, and for the advancement of steel gun construction in this country, that the two guns should have failed so soon in the proof. It is not fair to argue that it was the Krupp mechanism which caused the failure, since the steel was of unsuitable quality, and the after proof of the gun, with rounded angles, indicated a good endurance of the mechanism, as did also the proof of the experimental gun which endured 636 rounds without failure; but the failure of these guns called particular attention to that apparently ugly feature in the mechanism—the amount of metal cut away by the slot—which, especially in large guns, gives the appearance of longitudinal weakness. As to manipulation, and in other respects, the Krupp mechanism, provided by home manufacturers, gave a good degree of satisfaction. The only objectionable feature of importance noted was the tendency of the seat for the gas check to become oval, attributed to the presence of the slot and the resultant of the longitudinal pull which is sustained by the sectors of the metal left above and below, and is so unequally distributed throughout the cross section of the jacket. In the converted 3.2-inch breech-loading field guns this mechanism has given no serious cause for complaint in the limited use to which it has been put in our service. In Germany, however, it has been found necessary, in rough service, to modify the Broadwell ring. The large surface of contact

between the exterior surface of this ring and its seat makes it difficult to preserve the close adjustment needed, and this ill fitting is aggravated by the presence of any dust or dirt in the seat. The modification, which has been applied with good results, consists essentially in reversing the contour of the ring and limiting the surface of contact to a blunt rounded lip which comes in contact with the seat, to seal the escape of gas, only at the forward end of the ring. As regards the utility and safety of the Krupp breech mechanism, as a whole, its long-continued and successful application in guns made by Krupp place it beyond doubt as one of the two best systems now in vogue.

The effect of the failure of these guns in producing an unfavorable opinion upon the use of steel in gun construction was also marked. Not only was this opinion generally diffused, but it was taken up by officers of our own service and others interested in the science of gun construction. So it was uphill work with this metal for some years afterwards to convince such doubters that there was taking place a vast improvement in quality gained by knowledge and experience in its manufacture. Until finally, with more knowledge of the quality of the metal required for guns, all must now turn to steel to get a metal that can be readily made to exhibit the best combination of the qualities required.

The two remaining guns recommended by the Board of 1872 were the 9-inch Sutcliffe and the 12-inch Thompson breech-loading rifles. Both of these guns were made by the Government and tested at Sandy Hook, but the first was fired in all only twenty-six and the latter two rounds. Following this, in 1876, the pieces were sent to Philadelphia for exhibition at the Centennial, after which they were again returned to Sandy Hook. But thereafter no experiments were made by reason, as it appears, that no specific appropriations for the purpose were made by Congress. In each of the succeeding years, 1878, 1879, and 1880, the Chief of Ordnance recommended without avail an appropriation of $117,600 for the tests of these guns, including the Woodbridge 10-inch rifle, the Lyman multicharge gun, and the Mann 8-inch breech-loading rifle.

SUTCLIFFE 9-INCH BREECH-LOADING RIFLE.

In general construction this gun consists of a cast-iron body with a comparatively thick steel tube inserted from the rear and terminating at the front of the block, while in rear of the block and its slot the cast-iron body is bored and threaded to receive a movable hollow screw sleeve, which supports the block from the rear and through which the charge is inserted. The breechblock is made in the form of a disk, and is moved in its slot by rotating the sleeve. A Broadwell ring is used as a gas check. It was the intention in

making this gun to provide both for a test of the breech mechanism and the principle of steel lining in a cast-iron body, and the dimensions given to the parts were considered sufficient to enable the bore to be enlarged to 10 inches after firing 250 rounds, as a 9-inch gun. The tube was inserted with a slight play in the casing and was forced home by hydraulic pressure. Shoulders on the exterior of the tube prevent its forward movement, and it is also held by a screw muzzle collar and by a couple of securing pins through the casing. A powder chamber 0.3 inch larger in diameter than the bore is provided, and its axis is eccentric with that of the bore, being placed 0.05 of an inch above it. In the 26 rounds fired the heaviest charge contained 45 pounds of powder and a 250-pound projectile. The maximum pressure observed was 29,250 pounds per square inch. The test gave no measure of the strength of the system of tubing, owing to the limited number of rounds fired and the surplus of strength for a 9-inch gun, but in any event the breech mechanism constitutes its most interesting features. It is difficult to explain such features without the aid of a drawing, but an idea may be had of the slot in which the block moves by supposing one side of the Krupp slot left solid and the opening made in one side only. The block which moves in this slot is a disk of steel—in this gun 12.4 inches thick, or, say, 1½ calibers—which is moved by means of a steel pin connecting with the movable screw sleeve operated from the outside rear. The pin is set in the block near its periphery and is free to revolve in its seat in the sleeve. In giving the sleeve a half revolution the pin is carried around and the block is constrained to move in the slot, to open or close the breech, partly by rolling and partly by sliding. An obturator plate similar to the Krupp is embedded in the front of the block to support the Broadwell ring. The block is pierced with an axial vent. This breech mechanism has few parts and the motions are simple. It embodies the disadvantage of having an unequal section of metal through the breech just in rear of the place of maximum tangential strain, and where the longitudinal strain is most felt, but to a less degree perhaps than the Krupp mechanism. It also occupies a greater length of bore space than the French system. It might be claimed to have an advantage over this last, for longitudinal strength, because of the continuous thread of the breech screw, but the diameter of this screw must be made so great as to considerably reduce the cross section of metal that resists the longitudinal strain. But the difficulty found in operating it under fire, and that which appears to be the weakest point, is the inadequacy of the arrangement for controlling and moving the block. The stud pin which forms the only connection between the block and the breech sleeve is subject to severe strains, and in a few rounds fired it occurred that this pin became bent and the block was operated with difficulty.

THOMPSON 12-INCH BREECH-LOADING RIFLE.

This gun is made of a cast-iron body, of the usual Rodman model, in which is inserted, under a slight shrinkage, a thin steel lining tube that extends through the bore and is secured by a screw thread at the breech end. It was incomplete when received at the proving ground and in this condition was fired two rounds before being sent to Philadelphia in 1876, and thereafter, for reasons already stated, the test was not resumed. In the form of slot for breechblock it resembles the Sutcliffe gun. The face of the block when closed abuts directly against the rear end of the tube and closes the opening. The block is circular in cross section and is rolled laterally in the horizontal slot to open or close the breech. It is fitted with cogs which engage in a toothed rack laid in the bottom of the slot. Power is applied by means of a lever attached to a shaft or spindle which is secured to the center of the block and extends through the breech to the rear, and is there geared to work in a rack. On applying power the spindle and block revolve together and the spindle traverses a horizontal slot cut throughout the length of the breech along one side of the loading channel. The charge is inserted through the loading channel which forms a prolongation of the bore to the rear. The back of the block is faced with a cam, which, in the act of closing the breech, comes in contact with a corresponding cam on the rear face of the slot, by means of which the block is forced forward until its beveled face is in close contact with the end of the tube fitted to receive it—thus closing the breech. When closed, the block is supported in rear about its circumference, except across the opening made for traversing the spindle. The width of the cam bearing round the block is 1.5 inches.

When the gun was tried no means were provided for locking the block in position when closed, nor was there any provision for a gas check or vent proper. It was the intention of the inventor to use center-primed metallic cartridge cases, to be discharged by a firing pan passed through the center of the spindle and block. There are no features about this mechanism, I believe, which call for any special commendation in the light of present knowledge. The attempt to use a metallic case for a gas check was subsequently tried in the Yates 8-inch breech-loading rifle, with very poor success. The difficulty of holding the block up to place in the Thompson gun would be a serious one, and it might be anticipated that the bearing surface of the block in rear would prove insufficient, and the longitudinal strain to cause disruption of the breech would be besides wholly thrown upon one angle in the slot.

FIELD GUNS.

During the period 1873 to 1882 trials were also made at Sandy Hook with breech-loading field guns, and the Dean 3.5 mandreled

bronze gun. The Dean gun was procurred in 1877. It was subjected to a firing test of 50 rounds which, so far as it went, proved the excellent quality of the material, but it was a muzzle-loading gun, made after a design already out of date, and gave inferior ballistic results. The introduction of steel in new constructions operated against the extension of the system. This system of manufacture has been tried in Russia, Italy, and especially in Austria, where, under General Uchatius' earnest supervision, it was finally introduced for field and the lighter siege guns, but was not successful in application to heavier guns.

The three systems of field guns principally tested were the Sutcliffe 3-inch, Moffat 3.07-inch, and the converted 3.2-inch field gun with Krupp mechanism, made on the plans of the Constructor of Ordnance.

The Sutcliffe breech-loading field gun was made by converting a 3-inch wrought-iron rifle, the breech mechanism being in all essential respects like that of the 9-inch gun. The trial gun was received at the proving ground in 1876; it was fired 53 rounds, an average charge being 1¼ pounds of powder and a 10-pound projectile, which gave a velocity of 1,109 f. s. The reports state that, so far as tested, the working of the breech mechanism was satisfactory.

The Moffat breech-loading gun was brought out in 1873. The body is of steel, made from a solid piece. The breechblock, as in the Mann gun, is secured by a strap or breeching pivoted on the trunnions; and each arm of the strap is supported by locking into lugs on either side of the breech of the gun. The strap rests upon the head of the elevating screw, and the breech is raised clear of it for loading by means of a lever pivoted on the screw. The block is hinged to the underside of the breech, and has a conical face which fits closely in the breech. The rear of the block is wedge shaped, and in closing is pressed into its seat by contact with the strap. When the breech of the gun is raised for loading, the block revolves backward and rests upon the strap. This gun was fired 175 rounds, and gave a velocity of 1,124 f. s. with a charge of 1¼ pounds of powder and 10¼-pound projectile.

The converted 3.2-inch breech-loading field gun, Krupp mechanism, was first proposed in 1878, and trials were made with a gun of 3.17-inch caliber in 1879. Subsequently the caliber was increased, and the 3.2-inch was decided upon. The conversion consists in cutting off the breech of a 3-inch wrought muzzle-loading rifle near the bottom of the bore and screwing in from the rear a steel breech receiver through which the bore is prolonged. The breechblock is supported in the breech receiver, which also extends forward some 16 inches within the wrought-iron body, inclosing the chamber

and forming the rear portion of the bore. The breechblock is of the Krupp pattern made in this country, and the Broadwell ring is used for a gas check. By chambering, the power of this gun was much increased over that previously obtained with guns of like caliber, and as its trials were satisfactory, the gun was provisionally adopted for trial in service. A few have been made and issued for service and are still in use. In trials reported in 1883 the first gun shows a record of 849 rounds as far as tested. In prolonged firing the principal difficulty was found with the gas check, which became scored and allowed the escape of gas. With a new gas check 275 rounds were fired without material injury, and it was concluded that one check would be good for about 300 rounds. The powder charge is 3 pounds, and the solid shot weighs 12 pounds. With this charge the pressure averages 25,633 pounds, and the muzzle velocity is 1,548 f. s. The range at 20° elevation is 5,879 yards, or 3.34 miles; at 15°, 4,978 yards; at 10°, 3,986 yards, and at 5°, 2,508 yards. The gun weighs 826 pounds, and the muzzle energy of shot per pound of piece is 541.2 foot-tons.

To sum up the results of the ten years ending in 1882, which were devoted to the development of guns recommended by the board of 1872 (appointed by act of Congress): The Woodbridge brazed, wire-wound gun, and the Hitchcock gun, were thoroughly tried with results already mentioned—the former presenting great difficulties in manufacture and failing under proof, and the latter failing in manufacture. The Sutcliffe 9-inch, Thompson, and Mann guns were tested to a very limited extent, with results in the case of the first two which did not at best give any marked prospect of success; but Congress, by its refusal to appropriate money for the purpose, negatived an exhaustive trial of them. Lyman's multicharge gun comes under the same category; however, tests already made at Reading with the same gun that was awaiting trial at this time indicate that the interests of the country did not suffer in the failure to test it further.

The successful issue of the period was the Ordnance system of converted muzzle-loading rifles whereby there was placed in service 210 8-inch rifles, each having at 1,000 yards range more than double the power and three times the accuracy of the 10-inch smoothbore which it replaced, besides made strong enough by the conversion to endure fully as many, if not more, rounds as a rifled gun than the old smoothbore would stand with its light charges. And however poorly these rifles may now appear in comparison with the modern gun, this much must be remembered—if a war should arise to-morrow they are the only reliable rifles that we have available for seacoast defense. The power of this gun to penetrate 8 inches of

iron armor with backing, or 6 inches of steel armor, at 1,000 yards range makes it effective against a large proportion of the war ships of the world. It would of course be of little use in firing against the heavily armored ships, but these constitute perhaps one-fourth only of the whole number of such ships.

The 11-inch rifle of the same construction was successfully tested, but was not made a service type, which was a wise course, seeing the relative disparity of this caliber to those of other countries, when it became a question whether to make these guns in quantity, and noting also the present efficiency of the 15-inch smoothbore with its increased charge. In other words, it did not then appear to be a paying investment—and, with our present knowledge, it would appear much less so—to sacrifice a 15-inch smoothbore to make an 11-inch muzzle-loading rifle. The converted 8-inch breech-loading rifle of the same general construction, with Krupp mechanism, unchambered, and firing a charge of 35 pounds of powder was a practical success. The principal utility of the proof of this gun lay in the trial of the breech mechanism; the gun proved abundantly strong to withstand the charge which was used, but the design could not be adopted as a service pattern, because it presented the disadvantage of increased cost with no corresponding increase of power or efficiency over the muzzle-loader. The next step in the development of this system was to obtain a satisfactory increase of power for the converted breechloaders (8 and 11 inch) by chambering to use a largely increased charge of powder, and to extend the system to new constructions of large caliber, with increased length of bore to give high power. The first 8 and 11 inch guns failed, we may infer, because of the square angles of the slot, although the steel used in them was not of suitable quality. The second 8-inch gun, with rounded angles in the slot and the same make of steel, burst at the one hundred and twenty-seventh round after enduring a series of high pressures ending with six consecutive fires, giving pressure running uniformly about 50,000 pounds and over. The inevitable conclusion from these trials was that this system of converted breechloaders did not possess the margin of strength which would warrant its introduction in service. The extension of the system to large calibers of new construction was abandoned, because it was impracticable to obtain a suitable quality of steel in the forms required by the design.

One lesson may at least be learned from what took place in these ten years, and that is that success in gun making depends not upon the test and trials of different plans, however numerous, but upon a steady and persistent effort upon one system; and when, as in our own country, the sums appropriated for such purposes are small in amount this course offers the only means of reaching any degree of success whatever.

III.

THE CONCLUSIONS OF BOARDS AND COMMITTEES APPOINTED BY CONGRESS—MONEY EXPENDED FOR THE PURCHASE OF CANNON DURING TWENTY YEARS—RECENT PLANS OF GUN CONSTRUCTION—THE MULTICHARGE GUN—THE MANN AND THE YATES BREECH-MECHANISM—THE SLOTTED SCREW BREECH MECHANISM.

Coming now to a later period, the course of legislation in Congress, which governs these matters, has been such as to leave all questions of policy in a state of the greatest uncertainty, and we find the War Department laboring under the most adverse circumstances in endeavoring to further the manufacture of the best type of guns recommended by the Logan committee, or the Senate ordnance report of 1883.

Beginning with the appointment of the Getty Board in 1881, every year thereafter, except 1882, when the report of that board was under consideration in Congress, has been marked by the appointment of a new board pursuant to act of Congress, until finally the subject of boards reached a period of at least temporary exhaustion, when the report of the Fortification Board was brought out in 1886. In that year, and in the present, there was no board designated, but neither was there any fortification bill passed.

The Board on Heavy Ordnance and Projectiles, of which General Getty, an artillery officer, was president, was appointed pursuant to the act of Congress appoved March 3, 1881, and submitted its report in May, 1882. The Gun Foundry Board was appointed pursuant to the act of March 3, 1883; the Armament Board pursuant to the act of July 5, 1884; and the Fortification Board pursuant to the act of March 3, 1885. Besides which, in the same years, we have had careful and detailed examinations and reports on the question of heavy ordnance from the Senate committee, of which Senator Logan was chairman, appointed August 2, 1882; the Senate Select Committee on Ordnance and War Ships, with Senator Hawley as chairman, appointed July 3, 1884; and a similar House committee, with Mr. Randall as chairman, appointed July 6, 1884. There is also the standing committee of the Senate, with Senator Dolph as chairman, which has charge of matters pertaining to ordnance. The Select Committees on Ordnance and War Ships of the Senate and House completed and submitted their reports in 1886. It is not my purpose here to analyze the able reports of all these committees and boards; they contain a vast amount of valuable infor-

mation upon the subject which we can only regret has been put to so little practical use, in so far as the land defenses are concerned. Of all the subjects treated in these reports (if we omit the Armament Board, which was convened for a distinct purpose apart from this question) there was one of all others upon which there is a unanimity of opinion, either explicitly expressed or directly implied, in their conclusions, namely: *That the solution of the gun question lies in the manufacture of the built-up forged-steel gun, and that the industry of making forged steel for such guns should be established in this country.*

Another matter which also received general commendation was that the recommendation of the Gun Foundry Board in regard to the establishment of Government factories (for the Army and Navy), with capacity to manufacture a limited number of these guns per annum, should be adopted.

But the conclusions of these committees and boards have been very useful in helping the Navy to get appropriations for this class of guns in the quantities needed for vessels in course of construction. And now that the policy of making them has been definitely inaugurated in one branch of the Government service, it will surely be extended to the land service. It has been said that the Ordnance Department has expended millions and millions on guns and has nothing to show for it. It may be useful information then to state the fact that the total amount expended for cannon in the twenty years beginning July 1, 1866, and ending June 30, 1886, by the Ordnance Department, did not exceed one and one-half millions of dollars. This does not include the amounts expended from the appropriations for *testing* experimental guns and various inventions, including dynamite, powder, projectiles, and material for service and reserve; but it does include the first cost of all the cannon procured in the twenty years, and in addition what had been expended upon those in course of construction at the end of the period. It covers the cost of the plant erected for the Woodbridge gun, the Hitchcock gun, the money otherwise expended for those guns, and all other experimental guns, and also of the following service cannon—318 in number—which are now in use or available for issue, viz:

1 20-inch and 26 15-inch Rodman smoothbores.
1 12¼-inch tubed muzzle-loading rifle.
5 11-inch
1 10-inch muzzle-loading converted rifles.
210 8-inch
4 8-inch breech-loading converted rifles.
1 12-inch muzzle-loading rifled howitzer.
1 8-inch breech-loading steel rifle.
7 3.2-inch converted breech-loading rifles.
25 3.2-inch steel breech-loading rifles.
36 steel Hotchkiss breech-loading mountain guns.

This sum of money, covering twenty years' expenditure for gun making for the War Department, is just equal to the amount allowed for the completion, exclusive of armament, of one of the new steel cruisers, for which we are expected to afford harbors of refuge.

RECENT PLANS OF GUN CONSTRUCTION.

We now turn to the guns of the present period, which, for authority to make by the War Department, are the outcome of the deliberations of the Senate Ordnance Committee of 1883, from testimony taken by that committee, from plans submitted to it, and from a review of the recommendations of the Getty Board of 1881. The recommendations of this committee were embodied in the fortification bill of 1883. That act authorized the continuance of the conversion of 10-inch smoothbores into 8-inch muzzle-loading rifles, and, in addition, the trial of 5 different systems of gun construction and two distinct types of breech mechanism, as follows:

1. Built-up forged-steel breech-loading rifles with slotted screw breech closure.
2. Cast-iron (simple) breech-loading rifles with slotted screw breech closure.
3. Combined cast-iron and steel built-up breech-loading rifles, and rifled mortars on the same system, with slotted screw breech closure.
4. Wire-wound breech-loading rifles.
5. The multicharge gun.
6. The Mann breech mechanism.
7. The Yates breech mechanism.

The two types of breech mechanism were selected by the Chief of Ordnance, under the requirements of the act which directed him to "select from the many breech-loading devices offered to the Getty Board and Committee on Ordnance two that promise the greatest success" for test at the cost of the Government.

The five systems of construction as such, based on various plans, had all, except the cast-iron rifle pure and simple, received the recommendation of the Getty Board. The simple cast-iron rifle was not recommended by the Getty Board, but was inserted in the act of 1883, as stated:

> In lieu of such of the guns the construction of which has not yet been commenced, as were provided for by the act making appropriations for fortifications, etc., for the fiscal year ending June 30, 1881.

The Government had procured the iron, and preparations had been made at the South Boston Foundry for the castings here alluded to, which were intended for the 12-inch breechloaders that could not be made for lack of a proper quality of steel for breech receivers.

Three of the systems, the built-up steel, the simple cast iron, and the multicharge, and the two types of breech mechanism contemplated in the act of 1883, have been subjected to trial; another, the combined cast iron and steel, has been submitted to partial trial

only in the proof of a 12-inch muzzle-loading rifled mortar hooped with steel, while the rifles made on the same system are in a more or less forward state of completion, which has been arrested for two years past through the lack of funds to pay for them, and the remaining one, the wire-wound, is in the same category as the guns just named; work on two of these wire guns, which has been in progress at Watertown Arsenal, is stopped for lack of money.

Of the plans of guns under consideration, all those exemplifying the built-up steel, the simple cast iron, and the combined cast iron and steel guns, were made by the Ordnance Office. The plans of the wire-wound guns are due to Doctor Woodbridge. Mr. Haskell is the exponent of the multicharge gun. The Mann and Yates breech mechanisms are designated by the names of their designers, and these gentlemen each supervised the construction of the gun embodying his plan. All work done, and material furnished for the manufacture and test of the guns has been at the expense of the Government, except for the multicharge gun, which was furnished at private expense, and the costs of the tests only paid by the Government.

THE MULTICHARGE GUN.

The principal feature of this gun is well known to consist in the application of the accelerating principle as applied to the action of the powder upon the projectile, and this is sought to be obtained by using a series of powder charges placed in pockets at intervals along the bore near the breech, which are intended to be ignited by the inflamed gases of the breech charge following the passage of the projectile over the opening of each powder pocket into the bore. The breech charge is relatively light to give a gradual impetus to the projectile, which is placed immediately in front of it and in rear of all the pockets. The mechanical difficulties in this construction are many, but two of the most important are: First, the necessity for a perfect closure of the gas escape at the base of the projectile, to prevent a premature ignition of any of the charges in the pockets; second, the difficulty of making a gun of this kind strong enough to withstand even the reduced pressures which may be obtained by an application of the principle. This last is especially important, for when we talk about safe pressures in a gun it is of course only a relative term and applicable to the particular gun under consideration. As for instance, a pressure of 50,000 pounds has been found quite as safe for a tubed converted gun with a cast-iron body as 27,000 pounds for the tubed multicharge gun with a cast-iron body, since both of the guns ruptured under these pressures; only that the converted gun stood a total of 127 rounds, and the multicharge a total of 33 rounds, before its first failure, and of 53 rounds up to final rupture.

The brief account that I can give of this invention is taken from statements made by its proprietors before the Board of 1872 and the Getty Board, and the reports of some officers who have witnessed its test. The system was patented by A. S. Lyman, who commenced to make experiments to test the merits of his invention to have it brought into use about 1856. Of the various experiments that may have been made we have accounts of the performance of three guns only, viz, a $2\frac{1}{2}$-inch gun tested at the Washington Navy-Yard, a 6-inch gun tested at Reading, Pa., in 1870, and the 6-inch gun which was tested at Sandy Hook, in 1883–84. The most striking experiments otherwise described were made with a so-called gun, but rather a small-arm tube, 10 feet 10 inches long, one-half inch caliber, giving the enormous proportions of 260 calibers length of bore. In this tube was arranged one breech charge and five additional pocket charges. The bullet was of steel, 18 calibers in length. It is stated that with a total powder charge of $8\frac{1}{2}$ ounces, and $7\frac{1}{4}$ ounces, in the steel bullet, a penetration was obtained through 12 plates of boiler iron bolted together; each plate was something over three-eighths of an inch, and the total thickness was $5\frac{1}{4}$ inches. This result showed a penetration of $10\frac{1}{4}$ calibers. The initial velocity of the bullet was not measured, but a computation by the engineer of the company made it 3,000 f. s. Carrying the same proportions, and assuming corresponding results with a 9-inch gun, there would truly appear, as an advocate of the system has claimed, a penetration of 7 feet $10\frac{1}{2}$ inches of iron armor, and he might have added the gun would be 195 feet long and the projectile $13\frac{1}{2}$ feet long. However, a better judgment can be formed by showing the actual results obtained with the guns constructed, as this is the only safe guide in such matters.

The $2\frac{1}{2}$-inch gun at the Washington Navy-Yard penetrated a target of wrought-iron plates 5 inches thick, backed by 18 inches of solid oak timber. This gave a penetration of "more than 2 calibers." The firing was done at point-blank range, 200 yards, with a total charge of $6\frac{3}{4}$ pounds of powder and a hardened steel projectile weighing $19\frac{3}{4}$ pounds. This gun was afterwards fired at Sandy Hook for velocity; the maximum obtained was 1,929 f. s. with 10 pounds of powder and 8-pound projectile.

An account is given of 13 rounds fired from the 6-inch gun at Reading, Pa., in 1870. This gun had four accelerating pockets and a total weight of about 11,000 pounds. The initial velocity was measured for 6 rounds, of which the best record is 1,093 f. s. To quote from Captain Prince's report of the trial which he witnessed:

The large local pressures and moderate velocities developed in this trial, where precisely an opposite state of things might reasonably have been looked for, can only be explained by supposing that the pocket charges in some cases became ignited before the projectile has passed over their *embouchures*.

This is the gun, I believe, which was taken to Sandy Hook for trial, pursuant to the recommendation of this system by the Board of 1872.

The trials at Sandy Hook in 1883–84 were made with a new 6-inch gun completed at Reading, Pa., in 1883. This gun, weighing 25 tons, was made of a cast-iron body, lined throughout its length with a steel tube, chambered for the breech charge, and having a length of bore equal to 46 calibers. A breech-closing mechanism enabled the insertion of the projectile and breech charge from the rear, and the four powder pockets were loaded by pouring the powder into a channel connecting with each pocket from the exterior. The typical method of loading consisted in using five different kinds of powder in the separate charges—relatively slow burning in the breech charge and increasing in fineness of granulation and quickness of burning for each successive pocket forward. In the later rounds of the proof this arrangement was modified to use two powders of the same granulation, but of different brand in the two pockets next the breech charge.

The proof was begun with a charge of 12 pounds of powder in the breech and the pockets empty. This round gave a velocity of 1,067 f. s., with a projectile weighing 108 pounds. Working gradually up by increasing the number of pockets loaded and the total powder charge at the same time, at the thirteenth round the full number of five charges was first used. In this round the total weight of powder was 83 pounds and projectile 109 pounds. The pressure within the chamber and pockets reached about 20,000 pounds, and the initial velocity was 1,735 f. s. The firing was then continued with varying charges of powder and projectiles up to the thirty-third round, when the tube was cracked over a length of 9 feet from the muzzle to a point near the foremost pocket. The pressure in these rounds varied in the different charge receptacles from a minimum of 18,000 to 29,000 pounds, which was the maximum record of pressure obtained from the gauges placed in the breech and in each of the four pockets. The highest record of velocity in this trial, which appears also to be the highest yet obtained from a 6-inch multicharge gun, was 2,101 f. s., obtained with a total powder charge of 96 pounds and a projectile weighing 71 pounds. The gun was then strengthened by shrinking several steel bands over the chase—the only part where the form of the gun admitted the employment of this strengthening process. The proof was then continued up to the fifty-third round, when the cast-iron body was cracked and the piece permanently disabled. The highest pressure that the gun had to endure in the proof was an exceptional record of 31,550 pounds—an average of the pressures with full charges being about 27,000 pounds per square inch. The best record of energy obtained during the proof was given with a total powder charge of 116 pounds and projectile four calibers in length weighing 152 pounds, for which the velocity was 1,801 f. s. and muzzle energy 3,422 foot-tons.

I have no desire to pose in public as a hostile critic of the multicharge system exemplified in the guns just mentioned, but rather the reverse, seeing the methods of attack that are used against those who honestly oppose it. A large amount of private capital has been expended in the attempts to perfect the gun, and experiments with it were earnestly pursued for many years. If the principle were really valuable, we should have expected in the latest model some conclusive evidence to that effect. The present status of these guns is a matter of public concern, and the conclusion which I draw from the actual results obtained is that the principle is not valuable in the present advanced state of the art of gun construction. A higher energy and a greater penetration than the multicharge gun has shown is a matter of every-day record with guns using a single charge of powder, and the greater effect of the single-charge gun is produced at a much less cost for original construction and for maintenance, and also with a much safer pressure in the gun. A pressure of 50,000 pounds, of which only about 70 per cent is needed for the service of the piece, is entirely safe for a single-charge steel gun, but what a multicharge steel gun would stand is highly problematical. A comparison of cast-iron lined construction has shown a better endurance for the single-charge gun under 50,000 pounds pressure than for the multicharge under 27,000 pounds. Probably the relative merits of steel construction would be about the same. Most emphatically, then, a higher energy has not been obtained with this gun, with its successive charges and with moderate and safer pressures, than can result from any gun of the same caliber using only one charge, nor is there any ground to hope that such a result can be expected.

THE MANN BREECH MECHANISM.

The principle involved in the Mann breech mechanism is to accomplish a complete separation of the longitudinal from the tangential strains due to firing a gun. As illustrated in the 6.5-inch rifle, tested in 1884, it comprises a heavy breechblock supported and threaded in a transom, having no connection with the body of the gun at the breech. The ends of the transom, which project beyond either side of the breech, are fastened in heavy side straps that extend forward and loop over the trunnions of the gun body. The gun body proper is made with a tube open from end to end, and is counterpoised at the trunnion bearings in the straps. The trunnions proper, which connect the whole system with the carriage, form a part of the side straps, and these straps support the longitudinal strain due to the pressure on the breechblock. The breech is opened or closed by raising or lowering the breech of the gun body, which revolves about its own trunnions. The breechblock when closed covers the breech end of the tube and supports the gas-check ring.

The Mann breech mechanism has been known and tried at different times for a number of years. Mr. Mann stated to the Logan Committee that in 1862 a 3-inch gun was fired at Battery Fox, Washington, D. C., 437 times under the direction of Admiral Dahlgren, and that during this firing the gun was fired 96 times in seventy-six minutes without interruption. In the same year the Navy Department gave him an order for an 8-inch breech-loading rifle made on the same plan. This gun was completed in September, 1873. A number of trials were made with this gun by the Navy Department, and it was then turned over to the War Department. Tests were made with it by Captain Edson, of the Army Ordnance Department, at Fort Monroe Arsenal, Virginia, in 1865. He found the working of the breech mechanism to be fairly satisfactory. This was the gun considered by the board of 1872, and pursuant to the recommendations of that board, and the plans of the inventor, the piece was altered in several particulars and transformed into a gun of 8.4 inches caliber. Previous to this transformation the gun had been fired fifty times. The only tests made of the piece after this were two rounds fired at the foundry, and eleven at Sandy Hook, in 1875. This record was sufficient to induce the Chief of Ordnance to select this mechanism, under the act of 1883, as one of the two, out of all those submitted to the Getty Board, which should be subjected to trial and test. A new gun, conforming to patents taken out by the inventor in 1882 and made under his supervision, was then procured at the cost of the Government. This gun, as already stated, was tested at Sandy Hook in 1884. The test was made under the Board for Testing Rifled Cannon, instituted as a permanent board by the act of July 5, 1884, which provides that hereafter all rifled cannon manufactured at the cost of the United States shall be publicly subjected to the proper test for the determination of the endurance of the same * * * and further, if such guns shall not prove satisfactory they shall not be put to use in the Government service. The history of this test is, in brief, given in the report of the board:

This gun, having burst at the twenty-fourth round, its endurance was not satisfactory to the board, and hence it can not recommend that it be put to use in the Government service. The highest recorded pressure was 27,500 pounds per square inch. The failure of the gun was occasioned by the fracture of the transom near its left tenon. This transom was made of a superior quality of Whitworth steel, and the fracture showed no defects in the metal. There was evidence during the firing that the side straps did not hold the breechblock up to its place, as the breech of the gun body was slightly raised from its place by the shock of discharge.

The principle of this breech mechanism appears to be a mistaken one; the longitudinal strain in a well-built gun does not materially detract from the tangential strength. Some constructions, as in the case of wire guns, may require a special provision to obtain the necessary longitudinal strength, but these should form an integral part of the gun, and be solidly and firmly built

into the structure. It would appear that any attempt made to separate the parts designed to withstand the two kinds of strain must either result in an essentially weak gun in one direction or the other, or else in the addition of a surplus, if not a useless, amount of metal to accomplish the object sought. Certainly in a built-up gun, such as was the body of the Mann 6.5-inch rifle, there exists no reason for such a complication as the attempt to separate the two kinds of strains. The trial was, however, a distinct test of the breech mechanism.

THE YATES BREECH MECHANISM.

The Yates breech mechanism is the subject of a patent issued June 28, 1881, to Colonel Yates, a retired officer of the Army. It is novel in principle and application, and consists of a couple of concave clamps (half sections) which, when closed, embrace the breech of the gun exteriorly, and are intended to afford longitudinal support to a solid head gas check or cartridge case of whatever nature that may be used within the breech end of the tube for the actual gas-sealing device. The gas check ring being a distinct feature, to be operated independently of the breech-loading device, is not to be understood as forming a part of it. To understand this distinction, without intending to draw a parallel, the Yates breech mechanism takes the place of the threaded block alone in the slotted screw system, or the sliding block alone in the Krupp system. A parallel can not be drawn, because, in each of the two systems named, the block forms a ready means for supporting or supplementing the gas check and making a complete automatic breech-opening device, while in the Yates plan there is no connection between the gas check and the rest of the mechanism; the breech is not opened or closed by the operation of the mechanism, but there is required, in addition, a heavy solid head gas check, which must be placed by hand in the breech end of the tube and removed in the same way for every round fired.

The "clamps" form a shell or envelope for the entire breech of the gun divided into two equal parts or sections which meet in a vertical plane through the axis of the gun. The front of each clamp is hinged (in common) well forward on the reenforce of the gun, and grooves or shoulders are cut circumferentially on the interior of the clamps which when the sides are closed hook upon corresponding shoulders cut around the reenforce of the gun and afford longitudinal support to the clamps. The shell formed by closing the clamps comes to close bearing over the breech end of the tube to support the gas check. The sides open to uncover a little more than the diameter of the bore at the breech. The opening and closing is done by means of a lever attached to the underside of the breech of the gun and pins on either clamp, which work in grooves cut in the lever. When closed, the clamps are held together by an outside latch fastening placed above

the axial line of the gun. This, at least, was the original arrangement; and the axial line was occupied by a firing device intended to insert a pistol cartridge to be used in firing the charge, but the latch fastening broke away after firing a few rounds, and was replaced by a locking disk; and a radial vent was made to be used instead of the axial vent.

The trial of a gun fitted with this mechanism was made by the Board for Testing Rifled Cannon at Sandy Hook in 1885–86. The gun, made at the cost of the Government, was an 8-inch rifle converted from a 10-inch Rodman smoothbore. The work was done at South Boston, under the supervision of the inventor. The breech of the smoothbore gun was shaped and bored through, and the muzzle lengthened by screwing on a cast-iron extension piece. The whole was lined with a close-fitting steel (Nashua) tube, making a chambered gun body of 20 calibers length of bore. In applying the exterior parts of the breech mechanism to this gun, the outside of the reenforce was necessarily turned off to provide the shoulders for the support of the clamps. To complete the breech closure—that is, to close the rear end of the bore and prevent the powder gases from acting in and through the unsealed joint at the junction of the clamps—the inventor designed a cartridge case of bronze, 12 inches total length with thin walls, and heavy solid base weighing 48½ pounds. This case was tapered on the outside corresponding to a seat made for it in the chamber of the gun to facilitate withdrawal; and to provide against sticking a slot was made in the rear of the tube to catch the head of the case with a hand-extracting tool. This case was intended to be used for repeated firings, but was necessarily withdrawn after each round—the work being done by hand as a distinct operation of opening the breech.

The gun was fired, in all 312 rounds, when it burst through the body, and the breech mechanism was destroyed by the rupture of the body. Except for the breaking of the latch in the early firings, there was no failure of the breech-loading device, but the trial developed its unsuitability as a breech mechanism. The board pronounced the separation of the gas check from the mechanism to be a "clumsy, inconvenient, and objectionable" feature as proved by the trial; and found that the "obturation was imperfect," the gas checks "not satisfactory" and besides, "heavy" and "difficult to handle," and "liable to serious injury from accidental dropping or striking against objects in rapid firing." In the 312 rounds fired, 11 different forms or dimensions of gas checks were tried and none was found satisfactory. No attempt was made by the inventor to employ a gas check which would not require the awkward handling mentioned. As a consequence of this serious defect the Yates breech mechanism,

as applied to guns of heavy caliber, is not at present a practicable breech-loading device.

It may be added, I think, as an objectionable feature in applying this mechanism, and the same feature is even more pronounced in the Mann system, that the complete truncation of the body directly in rear of the powder chamber, whereby the maximum tangential strain is required to be supported so near the end of the gun body, renders these systems liable to enlargement and very obnoxious deformation about the seat of the gas check. It also introduces a weakness against tangential strain, which could only be met by a substantial increase in the strength of the breech end over that required in the French system at least. Krupp does strengthen his guns at this place by shrinking on an additional hoop. Again the Yates plan necessitates a trimming down of the reenforce to get shoulders for the clamps, but he might, on the whole, still claim a margin of weight saving sufficient to make an extra heavy gun at the breech end.

The result of this trial of Colonel Yates' system in a gun of 8-inch caliber is an example of the difficulties which arise with an increase of the caliber; for I am informed that the device has been found to work well in pieces of small caliber, such as yacht guns.

THE SLOTTED (INTERRUPTED) SCREW BREECH MECHANISM.

In the breech-loading guns to be subsequently discussed—that is, in the experimental and standard types recently made or in process of construction, after the plans of the Army Ordnance Department and the Navy Bureau of Ordnance in the United States—the system of breech mechanism used throughout is the slotted screw.

This system owes its inception, as I believe, to Chambers' American patent of 1849 and to a further invention patented in this country by Schenkl in 1853, and was used in the construction of 6 guns made at Boston, Mass., in 1855 for the British Government after designs by an American named Castmann; but owing to clumsiness of construction these guns were not mounted.[a] The system was then taken up in France and gradually developed upon a working plan. It is shown and described in the Journal des Armes Spéciales et de l'État Major, V Série, Tome XII, 1864, page 199; VI Série, Tome II, 1868, page 161, and Armengaud's Publication Industrielle, Tome XX, 1872, page 297. The Journal des Armes Spéciales for 1868 states that these guns, of a caliber of 12, 16, 24, and 27 centimeters, had been adopted by the French for the navy, as well as for forts and coast defense.[b] As regards the United States there was then

[a] Holley's Ordnance and Armor, p. 608.

[b] See also Aide Memoire for Officers of Artillery, chap. 1, Paris, 1880. (Published by authority of the minister of war.)

no room for such development in the face of our (at that time) superior armament of heavy smoothbores. The system was officially recommended for trial by the Heavy Gun Board of 1872, having been especially brought to the attention of that board by Lieutenant Michaelis, of the Ordnance Department. That board also recommended other systems of breech loading, including the Krupp system, the tests of which have already been noticed. The slotted-screw system is now generally used in native gun making in France, Italy, England, and the United States. In France it is now mainly used in connection with the gas check of de Bange, who in 1873 first used an expansible pad of compressed asbestos and tallow for the purpose of transferring the pressure of the mushroom head to certain metal cups, which were thereby expanded radially so as to check the gas. Some countries still use the Elswick cup and the Broadwell ring to a certain extent in connection with the slotted-screw breech mechanism. In the experiments conducted by the Bureau of Ordnance of the Navy Department in 1883 and 1884 the de Bange gas check (which had previously been used only for field guns in France and elsewhere in Europe) was found useless for heavy guns, as the cups, when made of a large size, lacked elasticity and stuck so badly as to seriously interfere with the working of the breech mechanism in opening the breech. Much better success was obtained by the Davis gas check, patented in 1885, which retained the asbestos and tallow pad, but checked the gas by the radial expansion of the thin edges of steel disks or rings.[a] Hence the term "French breech mechanism" is applicable only in a general way to the various mechanisms which embody the slotted screw as used in the United States and elsewhere.

The Krupp breech mechanism is, of course, extended in use to a number of foreign countries where sales of his guns are made, and it has been adopted in manufacture in Russia. It is not my purpose here to discuss the relative merits of these two systems of breech mechanism. It may be doubted, indeed, if there is much room to choose between them, since both have been so thoroughly tested and proved. It may be remarked, however, that the slotted-screw system has been generally received by gun makers in choosing between one or the other with more favor than the Krupp, and probably the principal reason for this is that the Krupp requires a forging of larger diameter for the block-carrying cylinder than does the slotted screw, which may even be attached in the tube forging itself. The size of the required forgings for 12-inch rifles, it will be recalled,

[a] The Gerdom gas check, patented in 1895, is, however, more nearly perfect and has gradually superseded the Davis. In this device the asbestos and tallow pad is placed between resilient steel rings of peculiar cross section, made of about 0.02 inch greater diameter than that of the gas-check seat.

and the inability of the English makers to produce them of requisite quality, was what stopped the extension of the Krupp system in our own service. A possible reduction in the size of forgings is, of course, always a desideratum, and especially so in a country where the manufacture of steel forgings is a comparatively new industry. It undoubtedly also requires the best quality of steel to carry the Krupp block, and where a cast-iron body is used, as in some of our present constructions, the slotted-screw block is a necessary adjunct. It may be said, then, that we are now using the slotted-screw system, because it is one of the only two that have been proved reliable and satisfactory; and of these it is the one which, on the whole, is best adapted to our requirements and resources. These remarks do not apply with the same force to small as to larger calibers, but it is expedient to have a uniform system for all calibers.

IV.

CAST-IRON RIFLES—RODMAN, ATWATER, AND WIARD GUNS—12-INCH BREECH-LOADING RIFLE, MODEL OF 1883—MERITS OF SYSTEM DISCUSSED.

I have already stated that the trials of cast-iron rifles, pure and simple, were practically abandoned in the United States in 1871. That was a consequence of the terrible damning that cast-iron guns received at the hands of the Select Committee on Ordnance in 1869; and the recommendation of the Chief of Ordnance two years later, that no cast-iron rifles should be made for service, was the direct consequence of the bursting of a 12-inch Rodman cast-iron rifle at the twenty-seventh round. Up to the time when the subject was revived by the recommendation of the Logan committee, in 1883, fourteen years had elapsed since the casting of the last cast-iron rifle, pure and simple, procured by the War Department. This gun was a 10-inch rifle made at South Boston, in 1869.

Seven muzzle-loading cast-iron Rodman rifles, viz, 3 8-inch, 1 10-inch, and 3 12-inch, were procured by the War Department between 1861 and 1869. Their principal dimensions, weights, and qualities of metal were as follows:

Caliber of gun.	Made at—	Length of bore in calibers.	Thickness of walls.	
			Over chamber maximum.	At muzzle minimum.
			Calibers.	*Inches.*
8-inch	Fort Pitt, 1862	15	1.5	4.1
8-inch	South Boston, 1865	17.5	2.0	4.0
8-inch	....do	17.5	2.0	4.0
10-inch	South Boston, 1869	15.85	1.75	5.5
12-inch	Fort Pitt, 1861	14.0	1.5	6.5
12-inch	Fort Pitt, 1868	14.0	1.5	6.5
12-inch	South Boston, 1868	14.0	1.5	6.5

Caliber of gun.	Weight of rifle.	Character of rifling.	Physical qualities of metal.	
			Tenacity.	Density.
	Pounds.		*Pounds.*	
8-inch	15,996	Polygroove	30,416	7.2886
8-inch	22,160	For grooved projectile.	34,625	7.2980
8-inch	22,220	Polygroove	34,505	7.2980
10-inch	40,700	.....do	32,600	7.3063
12-inch	52,005	.....do	30,480	7.2250
12-inch	52,225	.....do	36,744	7.2903
12-inch	51,980	.....do	34,166	7.2963

The 8-inch Fort Pitt model, of 1862, had the outside lines of the 10-inch smoothbore, giving it the same thickness of metal as the converted muzzle-loading rifles afterwards made from these guns. The two 8-inch South Boston models, of 1865, were special designs prepared by Rodman, and were of heavy proportions, having 2 calibers thickness of wall in the reinforce and weighing 6,000 pounds more than the first model, the only compensation being an increased muzzle length of 2.5 calibers. The 10-inch rifle had a thickness of 1.75 calibers over the seat of the charge and a length of bore less than 16 calibers, dimensions which in built-up steel guns are altered to 1.16 calibers thickness for a rifle with 32 calibers length of bore. The 12-inch rifles had a thickness of 1.5 calibers over the seat of the charge and 14 calibers length of bore. The physical qualities of metal in all these guns was fully up to the standards of tenacity and density now attained, or that can be attained in cast-iron gun metal.

The proof of these guns was concluded in 1871, except for the 10-inch. The following shows their endurance:

Caliber of gun.	Made at—	Average full charges.		Number of rounds endured.	Trials concluded.	Remarks.
		Powder.	Projectile.			
		Pounds.	*Pounds.*			
8-inch	Fort Pitt, 1862............	15	150	1,047	1865	Gun burst.
8-inch	South Boston, 1865........	15	150	80	1866	Do.
8-inch	.....do.....................	15	150	845	1870	Firing suspended.
10-inch	South Boston, 1869........	40	300	70	1875	Gun burst.
12-inch	Fort Pitt, 1861............	55	500	472	1869	Do.
12-inch	Fort Pitt, 1868............	60	600	27	1871	Do.
12-inch	South Boston, 1868........	64	624	2	1868	Firing suspended.

The maximum powder charge, fired from the 12-inch rifles, was 70 pounds. Some projectiles of 675 pounds weight were also fired, and a few of 700 pounds; but the charges given in the table were rather above than below the average and are absurdly small in comparison with those of the present day. The second 8-inch gun on the list was rifled with five lands, separated by broad grooves, and the projectile was grooved to take the lands. The projectiles used in the remainder were fitted with soft-metal sabots, chiefly of Parrott, Dyer, and Dana patterns. These projectiles were the best procurable, and the trials were conducted with care—certainly with a strong desire on the part of the proof officers to make the best of the guns.

The pressures recorded to have been endured in some of the rounds fired, exceeding largely as they do the amount due to the explosion of a charge in its own space, are something remarkable in their way, and can only be attributed to defective methods of measurement. Here we find, for instance, two consecutive rounds fired from an 8-inch gun on the same day, and with precisely similar charges,

gave: One a pressure of 90,000 pounds with 1,154 feet velocity, and the next 23,000 pounds pressure with 1,044 feet velocity. In the records of these pressures we find figures of 150,000 and even 240,000. Some of the pressures were measured with outside pressure gauges, and the result of balloting of the interior pressure gauge in producing very erroneous measurements was not appreciated. In 1881 Capt. C. S. Smith tried the experiment of dropping the Rodman pressure gauge complete from the balcony of the Western Union tower at Sandy Hook. The housing, containing the knife, etc., was designedly dropped upon a stone at the bottom of the tower. The height was such as to make the velocity of fall 63 f. s. Even with this small velocity, the cuts made, on striking, corresponded in one trial to 46,000 pounds, and in the second to 35,500 pounds of pressure (Report Chief of Ordnance, 1882, p. 124). Noble and Able's experiments gave a pressure of about 94,000 pounds per square inch for a charge of powder exploded in a rigid envelope and completely filling its space. The action in the chamber of a gun can never equal that in a rigidly inclosed space, and the old theory that high pressures would be produced in a gun fired with a projectile not pushed home is entirely exploded by the beneficial results obtained from air spacing.

I am aware that the bursting of the guns has been attributed to the breaking up of the projectiles, wedging of bands, uncertain powders, and other causes which suited the interests of those who propounded these reasons, but I believe the true reason to lie in the frailty of the guns themselves. In the 8-inch steel rifle, now at Sandy Hook, for example, on two or more occasions, shot weighing about 300 pounds have been broken in the bore by the shock of discharge; yet, in these cases, neither was there any marked increase of pressure, nor was the gun in the least injured. And again, in the trials at Annapolis, two loaded shells have burst within the muzzle of the new steel guns without detriment to the guns.

Another 12-inch cast-iron rifle, tried in 1867, was the Atwater rifle. In this gun some of the lands were removed near the muzzle to decrease the friction of the projectile, and to illustrate some other ideas of the inventor. The gun burst at the thirtieth fire, the average full charge used being: Powder 55 pounds, and projectile 525 pounds. And there was also Mr. Norman Wiard's gun, generally known as the "cart-wheel" gun, which burst at the first round.

As an illustration of what cast-iron rifles will stand when *badly* treated, we may extract the four of this class which were included in Wiard's somewhat notorious experiments at Nut Island, 1873–1875.

Nature of gun.	Charge.		Projectile.		No. of rounds fired.	Remarks.
	Kind of powder.	Weight.	Kinds.	Weight.		
15-inch Wiard rifle, new gun.	Oriental mammoth.	50 140	Wiard conical..	453	19	Gun burst.
15-inch navy Wiard rifle converted from a navy 15-inch smoothbore.	....do..........	50 180	Wiard conical and subcaliber.	492	2	Do.
15-inch Wiard rifle converted from 15-inch Wiard smoothbore No. 1.	Oriental hexagonal.	55 70 100	Spherical and Wiard mitten.	450 529.5	7	Do.
11-inch Wiard rifle, new gun.	Oriental mammoth, oriental rifle, and Bickford rifle.	50 100	Wiard conical, copper veneered.	260	3	Do.

The Wiard rifles are generally admitted to have been destroyed by the use of excessive charges and bad projectiles, yet the charges he used bear no comparison with those now required to be used in steel guns.

We have now brought the record of endurance of all the larger calibers of cast-iron rifles, pure and simple, which were tested up to 1883. I could not, if I would, enter into the details of the experiments; that there may have been mitigating causes for some of the failures one would be rash to deny; but the general merit of a system is to be judged by its endurance under fire. And there are enough examples, not only of miscellaneous cast-iron rifles, but also of those cast on the Rodman plan, in the preceding records to enable anyone to decide that cast-iron rifles, pure and simple, have shown a very unstable quality, judged by their own day and generation. The supposition is not only reasonable, but it is undeniable that the Rodman rifles were tested with due exercise of care, nor was there any greater variety of charging than was demanded by the period to which they belong. This has always been a necessary accompaniment of the trial of experimental guns, and is a very marked feature in the experiments of the present day. Of the six Rodman rifles proved for endurance, as stated, three bore a good record and three a very poor record. The simple conclusion from the trials of the period is, that cast-iron rifles, pure and simple, were proved to be distinctly unreliable.

12-INCH BREECH-LOADING CAST-IRON RIFLE, MODEL OF 1883.

The design of this gun was prepared in the office of the Chief of Ordnance in common with all those representing the combined cast-iron and steel guns, and the built-up all-steel guns authorized by the act of 1883.

The gun is a 12-inch breech-loading rifle, weighing 54 tons of 2,000 pounds each, 30 feet total length, 4⅔ feet (56 inches) across the thickest part of the reinforce, and 24 inches across the muzzle. The exterior has the curved outline of the Rodman model, with the

thickness of the wall decreasing toward the muzzle, and proportioned to the powder pressure to be withstood in the different sections of the bore. The maximum thickness of the wall surrounding the chamber is 21¼ inches, or a little over 1½ calibers, expressed in terms of the diameter of the chamber; the thickness over the seat of the shot is also about 21 inches, or 1¾ calibers, and at the muzzle 6 inches, or one-half caliber. The bore is 28 feet, or 28 calibers, in length, of which the powder chamber, 13.5 inches in diameter, occupies nearly 5½ calibers; and the rifling consists of 60 lands and grooves 0.06 of an inch in depth, with a twist increasing from one turn in 135 calibers at the origin, to a uniform twist of one turn in 40 calibers, which covers a length of 33 inches next the muzzle. The full charge is 265 pounds of brown prismatic powder (density of loading 0.84 [a]) and a projectile 3 calibers in length weighing 800 pounds. The breech mechanism is the slotted screw system, and the steel block is held in a steel sleeve screwed into the cast-iron breech of the gun to the depth of the block recess. Excepting the parts of the breech mechanism and this sleeve, the gun is wholly of cast-iron and is in one piece, cast with a core on the Rodman plan and cooled from the interior to produce initial tension.

The gun was made under the supervision of the Ordnance Department, by contract with the South Boston Iron Works. Eight months were occupied by the contractors in preparing for and making the casting, and eighteen months in all in finishing the gun. The casting was made breech end up, with a riser of the full diameter 7 feet long. Initial tension rings taken from the breech, and from the muzzle, and cut through on a radius in the usual manner, gave values of initial tension equaling 15,750 pounds for the breech end and 3,500 pounds for the muzzle end.

The firing tests were conducted at Sandy Hook before the Board of Testing Rifle Cannon. The report of that board upon tests made to date will be found on page 113, Report of the Chief of Ordnance, 1886. In all, 137 rounds have been fired:

[a] "Density of loading" is the density of the products of combustion of the powder charge, when expanded to fill the powder chamber, referred to water at a standard temperature and density, as unity. Its value is expressed by the quotient:

$$\text{Density of loading} = \frac{\text{Weight of charge expressed in pounds.}}{62.5 \times \text{volume of chamber space expressed in cubic feet.}}$$

	Powder charge.	Projectiles.
	Pounds.	*Pounds.*
1 round	100	700
Do	200	700
Do	230	700
6 rounds	150	700
2 rounds	225	700
Do	245	700
1 round	245	800
3 rounds	265	700
41 rounds	265	750
79 rounds	265	800

Of these, 123 rounds were with full charges of powder, and 79 with full charges of powder and projectile. The average pressure with the full charges, obtained by 100 observations (two pressure gauges being sometimes used with one charge) was 28,000 pounds per square inch, and a fair deduction from the test places the velocity to be obtained, with full charges, at 1,750 f. s. This is dependent, however, upon the use of the most suitable powder, the making of which is known to be a very difficult operation. The single full charge fired with German powder gave a velocity of but 1,710 feet with 31,400 pounds pressure. The best results were obtained with Du Pont's N. V. powder, of which five lots made at different times were tested, and gave variations (for full charges) from 1,690 f. s. with 25,325 pounds pressure to 1,809 f. s. with 34,000 pounds pressure. This last was the highest pressure to which the gun was subjected in the test, excepting one round, when the pressure gauge was dislodged there was indicated a pressure of 47,250 pounds, which is not considered reliable.

Taking the average result—charge 265 pounds, projectile 800 pounds, pressure 28,000 pounds, and muzzle velocity 1,750 feet—we find that the power of this gun is represented by a muzzle energy of 17,000 foot-tons, nearly.

The erosion of the bore became marked before the fifty-first round to such an extent "as to make star gauging very difficult." At the ninety-sixth round the erosions became pronounced, and increased rapidly toward the end of the test, when they became so serious as to lead the board to conclude that it would be unsafe to continue the firing with the gun, but it was thought that its life could be prolonged by the introduction of a steel lining. The star gauging, which appears to have been performed under difficulties, shows a general enlargement of something over one-tenth of an inch near the bottom of the rifling and thence decreasing quite uniformly to an inappreciable quantity at the muzzle. In the chamber the maximum general enlargement appears to be about 0.025 of an inch. It is difficult to give a clear idea of the extent of the erosions in this gun, especially as to their depth. The three most prominent gutterings are 5½, 10½, and 4½ inches in length, running nearly parallel to the

axis of the gun and distributed at the top and right side of the bore about the front slope of the powder and running into the shot chamber. The impressions indicate flared openings having a depth of about 0.15 of an inch, but can not show the depths of the fine extremities of the cracks.

Before drawing our conclusions from this new addition to the list of cast-iron rifles that have been proved and tested, there should be several points considered in reference to current methods of manufacture and changed conditions of service due to the introduction of slow-burning powder. It is claimed—

1. That the metal now made is better than ever before.

2. That the ability to make a casting with the core extending through the portion to be used for the gun body and casting breech up removes all the objectionable strains incident to Rodman castings of muzzle-loading smoothbores and makes a gun with the best condition of metal throughout.

3. That castings of any desired size and length can be made to give as high a power to cast-iron as to steel guns.

4. That existing facilities for manufacture or means ready at hand to be applied permit the prompt manufacture of a large number of cast-iron pieces at once—figures variously placed at something like 100 rifled mortars and 12 to 15 12-inch rifles per year.

5. That the introduction of slow-burning powders has made the use of cast-iron rifles safe, reliable, and economical.

The claim for superior quality of metal has no foundation in fact, as may be made apparent to anyone who will acquaint himself with the tests of metal made when the manufacture of cast-iron guns was a large and extensive business and the tests of the six large castings made within the last few years.

The extension of the core barrel through the gun body does not remove any objections heretofore existing to the Rodman method of casting, first, because the heavy solid breech in the muzzle-loading guns afforded an assistance not counterbalanced by the local strains occurring at the junction of the bore and base, and, second, because the principal objections taken to the Rodman method are not with reference to the strains located at this junction, but to those located along the barrel, where the results of the method are so uncertain. The method of casting the breech up has many objectionable features, which, probably, counterbalance any gain due to this method, but in this connection I may mention two circumstances: A reason for introducing this method here was because the Italians were using it; yet we are informed now that it has been abandoned in Italy because it does not give sound metal in the breech, where the greatest strength of the gun is required. And the third casting attempted at South Boston for the 12-inch tubed cast-iron rifle, made in this way, split longitudinally while still in the pit.

The limits of size and length of casting appear to have been about reached in those made for the 12-inch rifles, which required a weight of about 108 tons of metal and a casting some 40 feet in length in the rough; nor are existing facilities for manufacture such as would enable any considerable number of cast-iron rifles to be finished before we could, with home facilities, inaugurate a steady output of built-up steel guns. The only facilities existing at present in this country, for making long and heavy gun castings, are to be found at the South Boston Iron Works. What has been done there is shown by the following record of the time required to turn out 6 castings recently procured from that company, all requiring rough finishing only, except the first on the list:

No.	Nature of casting.	Date of order.	Date of casting.	Date of completion.	Remarks.
1	12-inch cast-iron rifle, simple.	Sept. 24, 1883	May 6, 1884	Apr. 1, 1885	Cast breech up with riser at breech 7 feet long.
2	Body for 12-inch tubed rifle:				
	First casting......	Sept. 24, 1883	July 9, 1884	....	Flask gave way and metal deposited in bottom of pit.
	Second casting ...	....	Dec. 23, 1884	....	Cast breech down, lower portion of flask surrounded by dry brick wall packed around with sand in pit. Casting broke across in several places in lathe.
	Third casting.....	....	Oct. 16, 1885	....	Cast breech up and ruptured longitudinally in pit.
	Fourth casting ...	....	Apr. 5, 1886	(a)	Cast breech up. Apparently sound casting.
3	Body for 12-inch hooped and tubed rifle.	Sept. 24, 1883	Oct. 31, 1884	Mar. 31, 1885	Cast breech down with riser at muzzle 18 inches long.
4	Body for 10-inch wire-wrapped rifle.	Sept. 24, 1883	Mar. 28, 1884	Sept. 1, 1884	
	Mortars.				
5	Body for 12-inch muzzle-loading rifled mortar.	Sept. 24, 1883	Mar. 1, 1884	Apr. 29, 1884	Casting delayed in procuring proper grade of iron and making trial cylinders for test.
6	Body for 12-inch breech-loading rifled mortar.	May 15, 1886	July 30, 1886	Sept. 30, 1886	

[a] Not completed June 20, 1886, when contract expired by limitation.

The simple cast-iron rifle, with which no accident occurred, was eight months in casting and eighteen in finishing; and the five castings ordered September 24, 1883, were not all made at the expiration of two years and six months. The founders certainly had very hard luck with the casting for one gun, which was only made at the fourth trial, and my purpose in calling attention to these matters is simply to show the time that has actually been occupied in such work and the risk and difficulties which attend an attempt to make heavy cast-iron rifles. The West Point Foundry could undertake the casting of the short bodies required for the hooped mortars, but with this exception I believe no other establishment than the South Boston Iron Works has at present any proper facilities for the work. The hooping of the

mortars with steel will delay the output but little and will give what has been proved to be a suitably strong construction. That 12-inch cast-iron rifles may even be cast as long as may be required for modern usage is much to be doubted in view of the experience quoted, but the added length would not give the *power* of steel guns because of the limitations of pressure imposed upon the cast-iron. Again, to increase the length of a cast-iron gun entails a large increase of the weight and cost, noting that in 1865, when General Rodman, in revising the model of his 8-inch cast-iron rifle of 1862, imposed an additional weight of 6,000 pounds to gain 2.5 calibers length of bore.

That the introduction of slow-burning powders has made it safe to use cast-iron rifles is doubtful, and, besides, is only half stating the question. They may be safe if the pressures are kept low enough, but with a pressure as high as 28,000 pounds produced by a slow-burning powder their endurance would be an uncertain factor. This pressure would work the metal well up to the point of rupture, while in steel guns the work of the metal is within its elastic limit and less than half its limit of rupture. The new 12-inch cast-iron rifle has withstood an average pressure of 28,000 pounds, including a number of somewhat higher pressures for a sufficient number of rounds to demonstrate its ability to withstand such pressures and to entitle it to be classed as a safe medium-power gun for the caliber. This much must be conceded, and it may be anticipated that equally good guns can be reproduced, but past experience of the uncertain strength of cast-iron rifles does not warrant the assumption that it would be safe to count upon such a result as a constant product of manufacture. In addition to this, the slow-burning powder is very erosive in its action, and of all the metals that might be used to form the bore of a gun, cast iron is probably the most easily eroded. We have a good example of this effect in the 12-inch cast-iron rifle, which began to show marked erosion about the fiftieth round, while the 8-inch steel gun shows none after 100 rounds.

A businesslike view of the problem—and it has been sufficiently investigated by both figures and firings—will show that a built-up forged-steel gun, giving 17,000 foot-tons muzzle energy at each round, is a cheaper investment than this 12-inch cast-iron rifle giving the same energy; that is, the greater endurance of the steel gun will enable it to continue to deliver such shots enough longer than the cast-iron gun to more than make up the difference in the original cost of the guns. And beyond this, the difference of cost is all in favor of the much lighter piece—the steel gun—for transportation, handling, and emplacement. This in itself is enough to establish the superiority of the steel gun, but it is not the most important consideration, which is, comparatively speaking, that *the steel gun is safe and the cast-iron gun is unsafe.* It is not necessary to go abroad

for a confirmation of this statement; it can rest upon a comparison of the records of cast-iron and built-up steel rifles made at home. It is a good confirmation, however, to know that the practice of the rest of the world proves the same thing.

The question whether cast-iron rifles shall be or shall not be made rests with Congress. If they are to be made, let them be ordered at once in the quantities determined upon, for there is certainly no need for further experiments in this line. Let us sincerely hope, however, that any action taken for their procurement will not interfere with equally prompt action toward procuring a full supply of built-up forged-steel guns; to fail in this respect would, in my humble opinion, be the poorest sort of economy.

The ability which the officers of the Ordnance Department have shown in designing so powerful a cast-iron rifle as the one lately proved is an earnest of their desire and capacity to carry out whatever Congress may direct. Had the 12-inch cast-iron rifle been made after a design presented to the Logan committee, that was to fire 150 pounds of powder with 700-pound shot and give a muzzle energy of but 10,000 foot-tons instead of the 17,000 foot-tons procured in the design actually used, but little interest would attach to a discussion of its merits here or elsewhere.

V.

Combined Cast Iron and Steel Guns—Rifled Mortars—Breech-Loading Rifles—Wire Guns.

Including the rifled mortars, there are three different types of this construction in hand at the present time, viz, a 12-inch breech-loading rifle, mainly of cast iron, but lined with a steel tube inserted from the rear, and forming about one-half the length of the bore; a 12-inch breech-loading rifle, with cast-iron body, strongly reenforced by a double row of steel hooping extending from the breech to a distance forward of the trunnions—the trunnions themselves forming part of one of the hoops—and a steel-tube lining, as in the first gun; and two 12-inch rifled mortars alike in general construction, but one is muzzle-loading and the other breech-loading.

12-INCH RIFLED MORTARS, MUZZLE AND BREECH LOADING.

These are short, rifled pieces intended for high-angle fire, and especially adapted for the defense of seaports. They throw a very heavy, elongated shell, containing a large bursting charge, to a distance of 5 miles with facility. The weight of shell is from 610 to 625 pounds, and its fall is sufficient to pierce about 8 inches of armor. In the Russian-Turkish war a 6-inch mortar firing from shore disabled two ironclads.

The arrangement of the pieces on shore will be made in groups of 16, as is proposed, placed in sunken batteries, and so trained that any desired number of the pieces in the battery can be fired in the same line of direction against a single ship. The most serious question raised respecting the employment of rifled-mortar fire has been in regard to its accuracy. Their employment in groups will do much to overcome this difficulty by greatly increasing the chances of hitting, and the problem of getting a very good degree of accuracy from a single piece is one that the gun makers will not allow to remain unsolved. Its solution seems to lie in the use of breech-loading pieces, and we have just commenced the proof of a mortar of this kind at Sandy Hook which promises the best results.

The first experimental rifled mortar—12-inch muzzle-loading—was completed in 1884, and proved 1885–86 by the Board for Testing Rifled Cannon. The reasons leading to the adoption of the muzzle-loader

for the first experimental type were because it was then thought that the old method of loading from the muzzle would be, on the whole, best adapted to such short pieces as combining simplicity and cheapness, together with less care and attention required in service as compared with the breech-loader. This piece has been fired 403 rounds, and is considered amply strong for service. A range of 8,260 yards (540 yards short of 5 miles) was obtained with this muzzle-loading mortar, firing a charge of 52 pounds of powder and 610 pounds projectile at an elevation of 45°, the flight being good and forty-one and one-half seconds in duration. Examples of the accuracy of fire obtained with full and half charges at different angles of elevation, are given in the table herewith:

Powder charge.	Elevation.	Number of rounds.	Mean range.	Probability of striking vessel 330′ long by 60′ broad.	
				Vessel normal to plane of fire.	With keel lying in plane of fire.
Pounds.	*Degrees.*		*Yards.*	*Per cent.*	*Per cent.*
26	28	5	3,427	35.3	98.75
26	28	10	3,490	38	99
26	60	5	3,321	16.5	66.6
26	60	8	3,260	13	44.04
52	28	4	6,935	18	61.66
52	28	10	7,142	12.5	41.32

The best record of accuracy given is a target of 10 shots, range 3,490 yards, showing a percentage of 99 hits for 100 shots on the deck of a vessel 330 feet long and 60 feet wide, lying with keel in the plane of fire, and 38 with the vessel lying normal to the plane of fire. And again at 7,000 yards range, for a target of four shots, the percentage of hits was 62 for the first position of the vessel and 18 for the second position. It was found necessary, in the firing, to use sabots—the Arrick pattern was found to be the best—prepared with care to give a certain degree of sensitiveness, and there also appeared some advantages in using them of different degrees of sensitiveness for full and half charges. These defects of material required for service, together with the generally unsatisfactory degree of accuracy and lack of uniform steadiness in the flight of the shell, led the Department to manufacture a breech-loading mortar, which, on firing for the first time a few days since, gave very satisfactory results. With a powder charge of 65 pounds and projectiles 625 pounds the measured range was 9,385 yards, or 5⅓ miles. Nine preliminary rounds were fired, and the flight of the projectiles was true and clean.

In general design these mortars show a short rifled piece of about 9 calibers' length of bore. The muzzle-loading mortar weighs 13½ tons, and the breechloader is three-fourths of a ton heavier. The latter is fitted with the slotted screw block and breech mechanism

embodying a new and special design of retracting gear. In general construction the two pieces are nearly alike. The principal part is a cast-iron body, which forms about two-thirds of the whole weight. On the outside of this two rows of steel hoops are shrunk on, extending from the breech forward over about two-thirds of the length of the piece. The trunnions are forged as part of one of the steel hoops, which is shrunk on in the same way as the others. Preparatory to making the first mortar an experimental compound cylinder—a counterpart of the body of mortar around the chamber—was made by shrinking two of the lot of hoops upon a cylinder of the iron for the purpose of testing the metals and verifying the shrinkages computed for the construction of the mortar itself. In this case, as in several other similar ones tried with the different types of guns—combined cast-iron and steel, cast-iron wire-wrapped, and all-steel guns—the results of these experimental constructions confirmed in a highly satisfactory manner the results anticipated by theory and the application of standard formulas.

These rifled mortars are apparently made very heavy in proportion to their length. The necessity for this arises from the heavy weight of projectile used, and because they are also subjected to a pressure which may easily reach 30,000 pounds per square inch, for it is necessary to use a relatively quick-burning powder. The ratio of weight of projectile is only 1 to 50. Cast iron is a cheap metal, and, if properly strengthened, appears well adapted to use in these pieces to make up the weight. A number of persons, actuated generally, no doubt, by good motives, but principally, as I must assume, because they have not carefully examined into the question, have wished to make these mortars of cast iron alone. The reason why it is not best to do this is because the simple cast iron would give no assurance of safety in the service of the piece. With the pressures used in these pieces, to repeat what has been said before, the cast iron would be strained to near its limit of rupture. By shrinking on the two rows of hoops—one row, unless the hoops were very heavy, would not be sufficient—the strain upon the cast iron when the piece is fired is reduced to somewhat less than one-half of what it would be if there were no hoops. The hoops, therefore, are shrunk on to give such a factor of safety as all structures demand, and none need this factor of safety more than do guns. Added to this the certainty of good metal in the hoops surrounding the cast iron where the strain is greatest relieves a constant source of anxiety regarding the unsoundness of heavy cast-iron castings. We know that the hoops will hold and that their presence will make up for a greater or less degree of imperfection in the cast iron. The strength of these mortars based upon strains that lie within the elastic limit of the steel hoops and about equal for the cast iron to those which fail to produce an appreciable permanent set of the metal, is nearly

27,000 pounds per square inch. That is to say, the *elastic* strength of the mortar, banded with two rows of hoops, just about equals the average strain anticipated in service.

12-INCH BREECH-LOADING RIFLES.

Neither of the large rifled guns of this system have yet been delivered, as has already been noted. The tubed gun has reached the stage preparatory to the insertion of the tube in the cast-iron body, and the hooped and tubed gun is completed, but can not be accepted until the necessary legislation has been passed.

The trial of the tubed gun may be looked forward to with some interest, as it may prove to afford a sufficient increase of strength to make a safe medium-power gun, principally of cast iron, and at the same time remedy the fault found in the erosion of a simple cast-iron rifle firing large charges of slow-burning powder. Both guns, the hooped and tubed one especially, belong to the transition period from cast or wrought iron to the built-up steel gun. But because we have delayed the adoption of all-steel guns in this country to so late a period and take them up not as an experimental but as an established system, we may well avoid the necessity of expending time and money on the further purchase of these composite guns, which ruled for a number of years in France and Italy.

The tubed gun was originally designed to have the steel tube wrapped with wire, and in that design, as does also the present design of the hooped and tubed gun, represents an alternative system of gun construction belonging to a period four years since. This was before we had made any substantial progress in the manufacture of gun-steel forgings in this country, and those designs, offering as they did a satisfactory amount of strength for the anticipated medium power of the guns, were brought forward to meet emergencies and home facilities. They also offered the advantage of giving orders to our steel makers for steel forgings of a size adapted to the early stages of that industry, and enabled them to acquire experience looking toward the manufacture of larger forgings, such as were figured in the built-up all-steel guns presented for manufacture at the same time. Meantime it became necessary to go abroad to purchase the larger forgings (tube and jacket) for the steel guns.

The tubed rifle, as it is now to be made with a simple steel tube, will have the same general dimensions and weight as the 12-inch cast-iron rifle already described. The tube does not extend through to the breech, but is cut off at the rear at the base of the powder chamber, and the breechblock is held in a steel sleeve screwed into the cast iron, so that the longitudinal strain will be supported by the cast-iron body alone.

The hooped and tubed rifle is two calibers shorter in the bore than the preceding and will weigh 53 tons. This gun, built up by the successive shrinkage of the cast-iron on tube and two rows of hoops on the outside, is, when compared with a simple cast-iron rifle, or even the tubed rifle, an exceedingly strong construction. The making of the gun itself, in pursuance of a systematic plan adopted by the Ordnance Department for built-up gun construction, was preceded by an experimental construction embodying a complete section of the gun through the reinforce—that is, a compound cylinder forming a counterpart of the gun section. The section of cast-iron cylinder used in this was cut from the body of the gun casting, and the steel parts were of similar material to the forgings made for the gun. The objects accomplished by this means were a verification of the shrinkages calculated for the gun and a practical test of the metals on the same scale as the gun itself. This gun will safely support an interior pressure of 38,000 pounds per square inch without exceeding the elastic limit of the metals, and thus affords at least double the assurance of safety to be derived from a simple cast-iron gun, which, under some 10,000 pounds less pressure, is strained to near the limit of rupture of the metal, and, although a shorter gun than the cast-iron rifle, it will, with the same chamber space, afford more power than that gun, and with safety. A large charge of powder may be used with a greater density of loading, and higher pressures, with higher velocities, even with the same weight of shot, will be attainable, and will give an increased energy.

The half tube is inserted with a slight longitudinal shrinkage, in addition to the circumferential, the object of this being to insure a close joint in the bore where the steel tube ends and the bore passes into the cast iron. The tube is also continued through to the breech, being threaded and screwed into the cast-iron body for a length of 26 inches next the breech. This portion forms a reinforce on the tube and admits of sufficient thickness of wall to cut the thread for the breechblock in the tube itself. The screw connection between the tube and the cast-iron body transmits the longitudinal strain to the body. The steel parts of this gun make up a little more than two-fifths of the total weight of the piece.

WIRE GUNS.

Two of these guns made after designs presented by Doctor Woodbridge are partly constructed. The work was under way at the Watertown Arsenal, but was suspended in June, 1886, through failure of appropriation for its continuance. On one of the guns, a 10-inch, breech-loading, wire-wrapped, cast-iron rifle, the wire winding is completed, and the gun has yet to be finished on the outside, bored,

rifled, and fitted with breech mechanism. The steel forgings and wire for the construction of the second gun—a 10-inch breech-loading steel rifle, longitudinal bars, wire wrapped—have been procured, but no portions of the gun have yet been put together.

The 10-inch wire-wrapped cast-iron rifle will have 28 calibers length of bore and weigh 29 tons. The cast-iron body weighs 17 tons, and is wrapped with 0″.15 square wire with slightly rounded corners, applied (for the most part) with a uniform tension at the rate of 41,000 pounds per square inch of section of wire for nearly one-half the length of the gun, beginning near the breech. The muzzle half of the cast-iron body is not covered. A steel trunnion band is shrunk on the outside of the wire, and the portion of wire in front of the band is covered by a steel sleeve, also shrunk on, which will transmit the thrust of the trunnion band to another steel hoop shrunk on the cast-iron body and backed up by a key ring screwed on cold. In the section surrounding the powder chamber the thickness of cast-iron is 9.835 inches and of wire 5.49 inches. This gun may be expected to stand with safety an interior pressure of 36,000 pounds per square inch, which is computed to be the pressure necessary to produce a tangential stress of 19,200 pounds per square inch on the cast-iron metal at the inner surface of the chamber. An interesting experiment embodying an investigation of the initial tension in the cast iron, and the effect produced by winding on the wire, the efficacy of the soldering proposed for the wire, and for general information regarding the construction of the gun, was conducted at the arsenal preparatory to commencing work on the gun. It comprised the construction of a complete section of the gun, and is described in Notes on the Construction of Ordnance No. 38, to which reference has been made in discussing the subject of initial tension in cast-iron guns. An important result of this experiment was the apparent inadequacy of the soldering process, arising from the failure of the solder to thoroughly penetrate the mass. The soldering, although it would afford some assistance in the longitudinal resistance, was intended especially to hold the wires together to prevent slipping in a circumferential direction when the gun is fired. Another object was to prevent the wire from unraveling if a strand were cut on the exterior by a hit from a shot or other accident. A full account of the construction of this gun, as far as progressed, including a discussion of the strains by Lieutenant Crozier, is published in the Report of the Chief of Ordnance for 1886, page 359 et seq. The wire-winding machine used in this work is also of Doctor Woodbridge's invention. The type of wire-wrapped cast-iron rifles was commended by the Getty Board as a cheap construction, coming within the manufacturing facilities of the country. The design presented is not considered by its advocates as at all presenting the highest type of wire gun.

The 10-inch steel gun, longitudinal bars, wire-wound, is intended to reprensent such a type. The design presents a gun weighing 22 tons, with 30 calibers length of bore. The wire winding extends from the breech to the muzzle. The tube is of steel, and extends entirely through the gun, so that the breechblock screws directly into it. One of the most important features of the gun is the means to be provided to give longitudinal strength. This consists of a casing of longitudinal bars or staves made to form a cylinder fitting the tube over about one-half its length from the breech, and is connected indirectly at its front end with the trunnion band and at its rear end with the breechblock. The steel tube and trunnion hoops for this gun were procured from Whitworth. The bars and the wire for both guns are of home manufacture. The steel bars and billets were procured principally from the Otis Iron and Steel Company, Cleveland, Ohio. The bars were cold rolled at the works of Jones & Laughlin, Pittsburg, Pa., and the wire drawn at Trenton, N. J., at the works of the Trenton Iron Company.

The Navy Department has in hand a 6-inch steel tube wire-wrapped gun. It is partly completed, but no work has been done upon it for some time past.

The tests of these guns when completed will best enable an opinion to be formed of their merits. The advantage of wire wrapping on the cast-iron body over steel hooping is not apparent, as the cast-iron body could be sufficiently strengthened, for the limit of its endurance, by the application of steel hoops, which would besides obviate the danger to be apprehended from any accident which might cut and loosen the outer strands of wire. Wire guns, however meritorious may be the designs projected, and even the results of firing tests of a number already constructed in other countries, have as yet scarcely passed the experimental stage. Their object being to enable the use of excessive charges the difficulty of making them a serviceable construction is enhanced. The mechanical difficulties of the construction enter in the attempt to make a compact and serviceable structure in combining the parts designed to resist the two kinds of strain. There are, however, able advocates of wire gun construction. It appears also that continuous endeavors are being made to perfect the system, and it is not my intention to discredit trials with this or any other system which embodies as much promise of success as does the wire gun construction.

VI.

STEEL-CAST GUNS.

At the last session of Congress, by act approved March 3, 1887, the sum of $20,000 was appropriated for expenditure by the Navy Department for the purchase and completion of three steel-cast, 6-inch, high-power rifle cannon of domestic manufacture, one to be of Bessemer, one of open-hearth, and one of crucible steel. In response to proposals, bids were recently received for two of these castings to be furnished rough turned and bored, from which the finished guns are to be made. The Pittsburg Steel Casting Company furnished the bid for a Bessemer casting, and the Standard Steel Casting Company that for the open-hearth, or Martin-Siemens, casting. The crucible steel casting was not bid for. The main features of the specifications in the bids are as follows:

Casting rough bored and turned.	Cost.	Elastic limit.	Tensile limit.	Ultimate elongation.	Reduction of area.	Weight of finished gun.	Length of finished gun.
	Dollars.	*Pounds.*	*Pounds.*	*Per cent.*	*Per cent.*	*Pounds.*	*Inches.*
Bessemer steel	3,300	40,000	80,000	7	7	11,000	193.53
Open-hearth steel	5,300	30,000	70,000	10	5	15,000	193.53

These guns when finished will be required to fire a projectile weighing 100 pounds with a muzzle velocity of not less than 2,000 f. s. and to stand the statutory test prescribed by the act of July 26, 1886, which for navy guns has constituted a test of 10 rounds fired as rapidly as possible. The dimensions of the steel-cast guns proposed are suited to reproduce the interior dimensions of the 6-inch Navy forged-steel guns, so that in order to produce the effect required, the charge of powder will be from 48 to 52 pounds, and the pressure probably not less than 15 tons. In weight and exterior dimensions the Bessemer casting will closely approach the navy gun, while the open-hearth casting will make a heavier gun by 4,000 pounds. The price asked for these rough-finished castings will, when the guns are finished and fitted, make the cost of one *exceed* and of the other not greatly less than the total finished cost of the 6-inch, built-up, forged-steel guns manufactured at the Washington Navy-Yard from materials entirely of home production.

The physical qualities of the metal bear a poor comparison with those obtained in forgings, as, for example, taking a piece of somewhat larger caliber, the forgings for tube of the 7-inch steel howitzer furnished the War Department by the Cambria Company gave, elastic limit, 47,250 pounds; tensile limit, 92,750 pounds; ultimate elongation, 21.1 per cent; reduction of area, 29 per cent.

We are not informed of the methods proposed to be used in the manufacture of these castings and can only await the trial of the guns to form conclusions. They mark the first step in an attempt to establish the manufacture of steel-cast guns in this country, and our great manufacturing facilities, together with the constant advances now being made in the art of steel casting, may enable us to overcome many of the difficulties encountered in like attempts already made in other countries. And as this is the first step in a matter which, if ever successful, will probably require a number of years to extend itself to the successful production of guns of 12-inch caliber and upward, it is perhaps unreasonable to cavil at the number and comparatively diminutive size of the guns now to be made. The trial of one 6-inch steel-cast gun of a given make may prove something in regard to 6-inch guns, but, in the face of past experience and present widespread distrust of the suitability of unforged (or unpressed) steel guns, can do little to predicate what result will be obtained with larger castings.

Another potent necessity for making the small calibers at present appears to lie in the capacity of the steel works for making such castings, for there is no doubt but that a special plant must yet be provided for making the larger calibers of steel-cast guns. This is one of the items of expense which, combined with others, will probably make the cost of production of a gun of large caliber quite as expensive if made in this way as if made of forgings and built up. The amount of metal used for the hollow castings made or attempted for 12-inch cast-iron rifles was about 240,000 pounds, or somewhat more than double the weight of the finished piece. The rule of double the weight holds good in heavy steel castings. Taking, for example, a 12-inch steel gun, the heaviest casting required for a built-up forged-steel gun of this caliber is 40 tons, to be cast in the simplest form of a solid ingot. This gives a rough-finished forging of 14.5 tons weight, also less than half that of the casting. Applying these rules to the massive casting of a 12-inch steel-cast gun, the weight of casting, if made hollow, would exceed 100 tons, and if made solid would exceed 120 tons at the least estimates allowable. And for this massive casting a special plant, flask, and all the adjuncts must be provided. If we go to 16 inches caliber, the comparison is 84 tons, as the heaviest casting for the forged-steel gun against not less than 250 tons for the steel-cast gun. Considering

the extreme difficulty of making sound steel castings of even a few tons weight at the present time, how long may it be before such castings as these can be manipulated? For guns of such caliber, then, it may be said the steel-cast system is, from present lights and practices, a question for the future.

The feasibility of making castings for steel-cast guns up to 10-inch caliber (weight of casting about 60 tons) seems within the reach of appliances that might be readily provided, but that such guns or even smaller ones can be made of good sound material possessing the requisite physical qualities to compare in strength, endurance, and power with built-up forged steel guns of the same caliber can not be conceded. To even approach this it would be indispensable that the steel-cast gun should be made with a proper degree of initial tension. The Rodman method of casting has been proposed, but whether intended to accomplish the introduction of initial tension or not has not been made quite clear by its advocates. The slow process of cooling incident to this method would cause the formation of large weak crystals in the castings, and apparently recognizing this the advocates of the method have proposed to remove all the initial tension strains by an after annealing. This would, moreover, appear to be a wise precaution, inasmuch as this method of casting is so uncertain in cast iron and would be much more so in steel, with its greater shrinkage and liability to crack from internal strains in the casting. If, then, the Rodman method is not used for the purpose of introducing initial tension, the hollow casting is certainly a bad form, as proved by Whitworth's trials and tribulations with it. The unsoundness found in the center of a solid cast ingot is in this case only transferred to the middle of the walls of the gun—a result in every way bad, and which no subsequent treatment can correct.

The idea embodied in the making of steel-cast guns, viz, that steel in a relatively weak condition is abundantly strong for the work required of a gun is a decided step backward. The work now required of a gun can not be measured by the days of Rodman and Wade. A steel-cast gun is essentially not a gun of equal strength, and no addition to the massiveness of the structure can make it so, but only add to the inherent difficulties. The greatest gun-making establishment in the world has gone through all these stages and found this to be true. After years of trial with the massive (forged) construction Krupp turned to making built-up guns.

The method of procuring initial tension in steel-cast guns seems to be that followed by the Otis Iron and Steel Company, who presented a steel cylinder to the War Department for test in 1884. The cylinder was cast solid, bored, and during three successive heatings in a furnace cooled from the interior. The initial tension thus produced, tried by the obscure method of cutting a full ring, was indicated to

be 16,000 pounds per square inch. The tests of specimens of metal taken from different parts of the cylinder, which was 5 feet long, 24 inches outside and 6 inches interior diameter, did not, however, warrant the making of a steel-cast gun.

It may be stated as a fundamental principle that to make a gun safe to withstand repeated firings without undue enlargement or rupture it should possess sufficient elastic tangential strength in its walls to meet the strain due to the pressure of the powder gases, and it is desirable to have a considerable margin above this. The elastic resistance of a simple cylinder—that is, one of neutral metal—expressed in terms of pressure of the bore can not equal the elastic strength of the metal (determined by specimen tests). If we call P the pressure and θ the elastic limit of the material, the elastic tagential strength of a simple cylinder may be determined by the formula.[a]

$$P=\theta\,\frac{3(R_1^2-R_0^2)}{4R_1^2+2R_0^2}$$

in which R_1 and R_0 stand for the exterior and interior radii. From this—

If $R_1=2R_0$,	thickness of wall	$= \frac{1}{2}$ caliber;	$P=0.5\ \theta$
If $R_1=3R_0$,	" " "	$= 1$ " ;	$P=0.63\ \theta$
If $R_1=4R_0$,	" " "	$= 1\frac{1}{2}$ " ;	$P=0.68\ \theta$
If $R_1=5R_0$,	" " "	$= 2$ " ;	$P=0.71\ \theta$

A value of θ equal to 35,000 pounds may be considered at least not too low for the metal to be had in a steel-cast gun. This gives the simple gun an elastic resistance of 23,800 pounds if the wall be 1.5 calibers thick, and 24,850 pounds if the wall be 2 calibers thick, and is certainly far from satisfactory in a gun which will be subjected to pressures of 36,000 pounds or more.

This leads to an examination of how much the elastic resistance of the gun may be improved by the introduction of a proper state of initial tension. An investigation of this question is given in Appendix B. The physical properties of the metal assumed for the discussion are:

$\rho =$ Force corresponding to safe compression of metal $= 40{,}000$
$\theta =$ " " " extension " $= 35{,}000$

The example is for an 8-inch gun in which the thickness of wall is taken equal to $1\frac{1}{2}$ calibers for the section in front of the chamber. This is in excess of the present designs of 8-inch built-up guns. Regarding the liability of the gun to fail under either radial compression or tangential extension of the bore, the limit of its resistance

[a] Formula (17) Notes on the Construction of Ordnance, No. 35.

becomes in the first case 38,156 pounds per square inch, but if we admit that the bore may be extended tangentially to the elastic limit the resistance would be 49,130 pounds per square inch. This assumes that the correct state of initial tension has been produced, a practical question which rests in the hands of the manufacturer to solve. But taking even the failing limit under radial compression we find that the introduction of a proper initial tension would increase the elastic resistance over that of a simple cylinder some 14,500 pounds. It appears that a thickness of wall equal to 1.5 calibers is well adapted to the problem, as it gives nearly the same value for the pressure which would cause the failing limit under radial compression to be reached and that which would produce an equal extension of the metal throughout the thickness of the wall in the state of action. A purpose of the discussion is also to call attention to what appears to be the best practical method of experimentation in order to obtain a knowledge of the actual state of initial tension introduced by any given process of manufacture that may be adopted. With this knowledge obtained and a careful record kept of the method of treatment it might be hoped to reproduce the same result in successive castings. A fundamental part of the operation would be to cause the tangential compression of the metal at the surface of the bore to be brought approximately at least to the elastic limit of compression of the metal (in this case assumed to be 40,000 pounds per square inch). This is indispensable to getting the best resistance that the gun will offer.

VII.

BUILT-UP FORGED STEEL GUNS—PROGRESS MADE IN THEIR CONSTRUCTION—PNEUMATIC DYNAMITE TORPEDO-GUN—COMMERCIAL VALUE OF GUN-FORGING PLANT—GUN SHOPS—CONCLUSIONS.

This type of gun, as we make it to-day, is the embodiment of Professor Treadwell's clear idea of a gun of equal strength, as announced in 1843; of Chambers' mechanical ideas of breech mechanism and of hooping in layers with the hoops of each layer breaking joints, patented in 1849; of Rodman's elegant exposition of the benefit of procuring initial tension in a gun, published in the same year, and finally of Professor Treadwell's extension of this principle to the application of layers of cylinders or hoops in making a built-up gun.[a] All these men were Americans, and were pioneers in announcing these principles, which cover about all the fundamental ones of the built-up gun. These ideas went on their travels and took root in Europe, where money *is* spent on guns and defenses, and where slowly, but surely, side by side with forged or pressed steel, there was developed at a comparatively recent date the modern type of built-up forged steel gun, which now undoubtedly holds an unrivaled place. The French worked up the breech mechanism, and Vavasseurs' practical application of Treadwell's first idea has introduced the jacket piece which performs the double function of affording the means to secure the requisite amount of longitudinal strength, and at the same time properly assists the remaining layers in resisting the tangential strains. The responsible officers of the Government realized some years since what was taking place, and like sensible folk concluded that it would be best to expend the public funds upon the best and the only good article in the market. The Navy Bureau of Ordnance, backed up by the Naval Committees of Congress with liberal appropriations, has been successful in doing this; the Ordnance Department of the Army has received appropriations sufficient only to make and test some experimental guns. Both have used their utmost legitimate efforts to make the production of built-up forged steel

[a] I am aware that Blakely's claim to this is in dispute with Professor Treadwell's. Both patents were taken out in the same year (1855), and Blakely at the same time announced the principle of "varying elasticity," but this latter finds no special application to-day, and there is little doubt but that Professor Treadwell's claim to originality in this matter is a just one.

guns entirely a matter of home manufacture, and have studied for themselves the principles of mechanical engineering involved.

What I shall have to say about these principles will give an outline of the studies of this nature which the officers of the Army Ordnance Department have made, and the knowledge which they have acquired by care and practice in the construction of experimental guns, and in efforts to improve the quality of the steel forgings. I will not be understood as disclaiming our great indebtedness to foreigners for the money and inventiveness and skill they have expended in establishing the superiority of the built-up forged steel gun; but we did not import mechanical engineers to teach us how to build these guns, and we in the Army hope very soon to be put in the present condition of the Navy—that is, to have placed at our disposal a *domestic* supply of the material required for making them. We already know that our steel makers are capable to make the very best grades of gun steel, and it has been shown, as in the case of the Navy Bethlehem contract, that the only requisite to placing an order for steel forgings in this country is that Congress shall appropriate a reasonable amount for their purchase.

The amount of oil-tempered and annealed gun steel forgings which the Ordnance Department has procured from home manufacturers, since 1883, somewhat exceeds 200 tons, which has been supplied by the Midvale Steel Company and the Cambria Iron and Steel Works. A list of the principal forgings, showing when and where made, etc., is given in Appendix A. The forgings were procured for the following purposes in built-up gun construction:

I. For experimental purposes incident to the making of guns.

(*a*) Shrinkage and specimen tests of steel hoops to determine qualities of metal best suited for purposes of gun construction based on method of treatment in manufacture (1883) (1).

(*b*) Construction of a compound cylinder representing a full section through the reinforce (around chamber) of 8-inch breech-loading steel rifle (1885) (2).

(*c*) Construction of same character for 12-inch muzzle-loading rifled mortar, cast-iron body (3).

1. Notes on the Construction of Ordnance, No. 25.
2. Notes on the Construction of Ordnance, No. 32.
3. Report of the Chief of Ordnance, 1885, page 209.
4. Report of the Chief of Ordnance, 1885, pages 277 and 314.
5. Report of the Chief of Ordnance, 1885, pages 317 and 321.
6. Report of the Chief of Ordnance, 1886, page 22.
7. Notes on the Construction of Ordnance, No. 39.
8. Notes on the Construction of Ordnance, No. 41.

(*d*) Construction of same character for 12-inch hooped and tubed breech-loading rifle, cast-iron body (4).

(*e*) Effect of contact with molten cast-iron, and temporary exposure to a high furnace heat, upon the qualities of oil-tempered steel (5).

I. For experimental purposes incident to the making of guns—Continued.

(*f*) Frictional resistance to longitudinal separation of finished steel cylinders, shrunk one over the other as in gun construction (6).

(*g*) Shrinkage and specimen tests of forged steel trunnion hoop to determine qualities of metal throughout the forgings (1886) (7).

(*h*) Examinations of the strains produced by oil treatment, and the effect of after annealing in removing injurious strains from the forgings (1887) (8).

II. For the manufacture of guns.

51 complete sets of forgings for 3.2-inch breech-loading field guns, steel.

1 complete set of forgings for 5-inch breech-loading siege rifle, steel.

1 complete set of forgings for 7-inch breech-loading rifled howitzer, steel.

50 complete sets of forgings for 8-inch muzzle-loading converted rifles, including tubes, breech cups and muzzle collars.

110 forged (rolled or hammered) steel hoops for 8 and 10 inch breech-loading rifles, steel, and two 12-inch rifled mortars, and one 12-inch hooped and tubed breech-loading rifle, cast-iron bodies.

In order to complete the experimental guns authorized by the act of 1883, the Department, being unable to procure in the United States forgings of the size required, has purchased from Sir Joseph Whitworth & Co. the following, which have all been delivered, viz: Five tubes (one 8-inch, two 10-inch, and two 12-inch short tubes), two jackets (one 8-inch and one 10-inch) and five trunnion hoops (one 8-inch, two 10-inch, and two 12-inch). Since these orders were filled the Midvale Steel Works has demonstrated its capacity to make forged trunnion hoops as large as 12-inch, having made one of these for the 12-inch breech-loading mortar, and has also succeeded in producing a complete set of forgings, tube, jacket, and forged trunnion hoop included, for an 8-inch steel rifle, the qualities of metal being satisfactory throughout.

The progress made in the manufacture of built-up forged-steel guns to date is as follows:

Twenty-six 3.2-inch breech-loading field guns, steel, have been completed; the forgings for 25 additional guns are on hand, and their manufacture has been commenced at the Watervliet Arsenal.

One 5-inch breech-loading siege rifle, completed and in preparation for test.

One 7-inch breech-loading rifled howitzer, completed and in preparation for test.

One 8-inch breech-loading rifle, steel; tested up to 101 rounds.

One 8-inch breech-loading rifle, steel; forgings procured and manufacture commenced at Watervliet Arsenal.

One 10-inch breech-loading rifle, steel; forgings procured and manufacture commenced at Watervliet Arsenal.

If one is disposed to ask why no more than this has been accomplished they may be respectfully referred to the Appropriations Committees of Congress, who, for two years past, have deemed it wise to make no appropriations for the armament of fortifications, and this has so crippled operations that the Department has been compelled

to discharge even the small force of skilled employees at the proving ground, and has been able to accomplish almost nothing in the way of completed guns, except for the smallest caliber. Its officers, however, have devoted this time of waiting to a close and careful study of the best methods to be pursued in the manufacture of gun-steel forgings, and of matters pertaining to gun construction; and the extensive and thoroughly practical experiments which the Department has conducted in the use of steel in built-up gun construction in the past four years has given its officers a confidence in this method which could not, perhaps, have been acquired more thoroughly in any other way. Added to this there has been an exhaustive test of the steel field guns, and a perfectly satisfactory test of an 8-inch steel gun up to 101 rounds. There is no scoring of the bore, and since the gun was hooped to the muzzle there has been no evidence of weakness or defect in firing 77 rounds.

The physical qualities of the steel forgings accepted is indicated by the following table, which gives the standards established from the results of tests of the forgings manufactured, viz, by the Midvale Steel Company for field, medium caliber, and seacoast guns, cylindrical hoops of assorted sizes and forged trunnion hoops; by the Cambria Steel Works, for medium caliber guns and cylindrical hoops of assorted sizes, and by Sir Joseph Whitworth & Co., for tubes and jackets for seacoast guns. But the figures given for cylindrical hoops and forged trunnion hoops of American manufacture represent nearly the minimum results obtained from actual tests made.

Designation of piece.	Length of specimen between gauge marks.	Elastic limit.		Modulus of elasticity.	Ultimate tenacity per square inch.	Elongation after rupture.
		Load, per square inch.	Extension per inch.			
	Inches.	*Pounds.*	*Thousandths.*	*Pounds.*	*Pounds.*	*Per cent.*
Tube	2.0	46,000	1.533	30,000,000	86,000	22.0
	3.0	46,000	1.533	30,000,000	86,000	20.0
	4.0	46,000	1.533	30,000,000	86,000	19.0
Jacket	2.0	50,000	1.666	30,000,000	93,000	19.0
	3.0	50,000	1.666	30,000,000	93,000	18.0
	4.0	50,000	1.666	30,000,000	93,000	17.0
Cylindrical hoops	2.0	50,000	1.666	30,000,000	90,000	18.0
	3.0	50,000	1.666	30,000,000	90,000	15.0
	4.0	50,000	1.666	30,000,000	90,000	13.0
Trunnion hoops	2.0	50,000	1.666	30,000,000	90,000	18.0
	3.0	53,000	1.766	30,000,000	95,000	15.0
	4.0	53,000	1.766	30,000,000	95,000	13.0

The 2.0-inch specimens pertain to field calibers, the 3.0-inch to medium calibers, and the 4.0-inch to seacoast guns. The modulus of elasticity, determined by tensile tests, has been found to vary between 28,000,000 and 32,000,000 pounds, the former for tubes and the latter for hoops, but the majority of the tests gave more nearly 30,000,000 pounds. The method of manufacture followed in the forgings made in this country has been to forge by hammer, anneal at a

high heat (at least as high as that at which pieces are subsequently treated for oil tempering), then oil temper, and subsequently anneal at a lower temperature than that used in the oil-tempering process. That Whitworth's process may become the established one in this country is highly probable, but the hammered forgings now made are excellent.

The hardness of this steel (somewhat softer in the tube metal) is about 21 as compared with copper at 3.33. And in the whole range of physical properties the metal admirably fulfills the requisites of gun construction, viz: A combination of *strength*, *stiffness*, *extensibility*, and *superior hardness* as compared with any other grade of steel or other metal adapted to the construction of guns now made or that promises soon to be made in suitable commercial quantities. The wide range of elastic extensibility, combined with great stiffness (or resistance to displacement), and a high range of reserve ductility, are the most valuable attributes of the metal.

The tangential strength of any properly constructed gun, unless there be a decided difference in the moduli of the metal composing the wall, is, in general, measured by the product of the movement, which is produced in the metal at the surface of the bore, into the modulus of resistance of the metal in the wall surrounding the bore. To make this clear, we will discuss only the tangential extension limit of the metal and neglect the "set" which might occur from excessive radial compression of the wall of tube. It is proper to observe this latter limit in deducting the shrinkages, etc., for the construction of a gun, but from the various resistances which go to assist the tangential resistance of the gun under fire we may assume that its resistance to an interior pressure is not reached until the metal at the surface of the bore is extended to its elastic limit of tangential or circumferential extension. And, further, it will be understood that we are now discussing an all-steel gun, whether built up or solid, or any gun of metal of nearly uniform modulus throughout.

With such premises the elastic tangential strength of any properly constructed gun, based upon the well-established fact that the most dangerous displacement of the metal, either in the state of rest or action, takes place at the surface of the bore, is expressed very approximately by the following formula:

$$P = C\,(a + b)\,E \qquad \text{(D).}$$

This equation is derived from (1) Appendix B, by placing:

$$C = \frac{3\,(R_1^2 - R_0^2)}{4R_1^2 + 2\,R_0^2}\,,\quad a = \frac{\rho}{E}\,,\quad b = \frac{\theta}{E}$$

In which P represents the pressure per square inch within the bore for the state of action; C is a constant whose value depends only upon the interior and exterior radii of the wall; a and b rep-

resent the limits of tangential compression and tangential extension in the metal of the surface of the bore for the state of rest and action, respectively, hence the sum (a+b) represents the whole range of dilatation of the bore when the gun is fired; and E represents the modulus of elasticity of the metal composing the tube and supposed nearly constant throughout the wall.

Taking, for example, a gun with thickness of wall equal to $1\frac{1}{2}$ calibers, $R_1=4R_0$ and the value of the constant C is 0.682, hence equation (D) becomes,

$$P=0.682\ (a+b)\ E.$$

Now to apply this to various guns:

(*a*) The built-up forged steel gun is one in which the principle of initial tension is applied with certainty, and the metal, at the surface of the bore, is compressed with exactitude to the limit of tangential compression in the state of rest. Hence the range of dilatation of the bore under the action of the powder gas pressure, to reach the limit of tangential strength, is expressed by the sum (a+b), or, by 2a if we consider a equal to b (in general, however, a>b).

The value of a—the elastic extension or compression per inch—taken from the table giving the physical qualities of the tube metal is 0.001533, and E=30,000,000. Hence the elastic resistance of the built-up forged-steel gun is:

$P=0.682\ (0.001533)\ 2\times 30{,}000{,}000=62{,}744$ pounds per square inch.

The application of this formula also shows why it is advantageous to the strength of the gun to have outside cylinders with a high modulus of elasticity relatively to the tube—always supposing that the tube combines a high degree of elastic extensibility in connection with its low modulus, for, in that case, the value of E, which in the formula represents the modulus of the tube metal, ought to be raised to about an average of the modulii of the metal in the different cylinders to reach an estimate of the resistance of the gun.

(*b*) In the case of a steel-cast gun *supposed* to have been constructed with a properly regulated initial tension. (See Appendix B.) If we retain the modulus E=30,000,000, and take a=0.001333 and b=0.001166, the relative values corresponding to $\rho=40{,}000$ and $\theta=35{,}000$ pounds per square inch. The elastic tangential resistance of the gun would be:

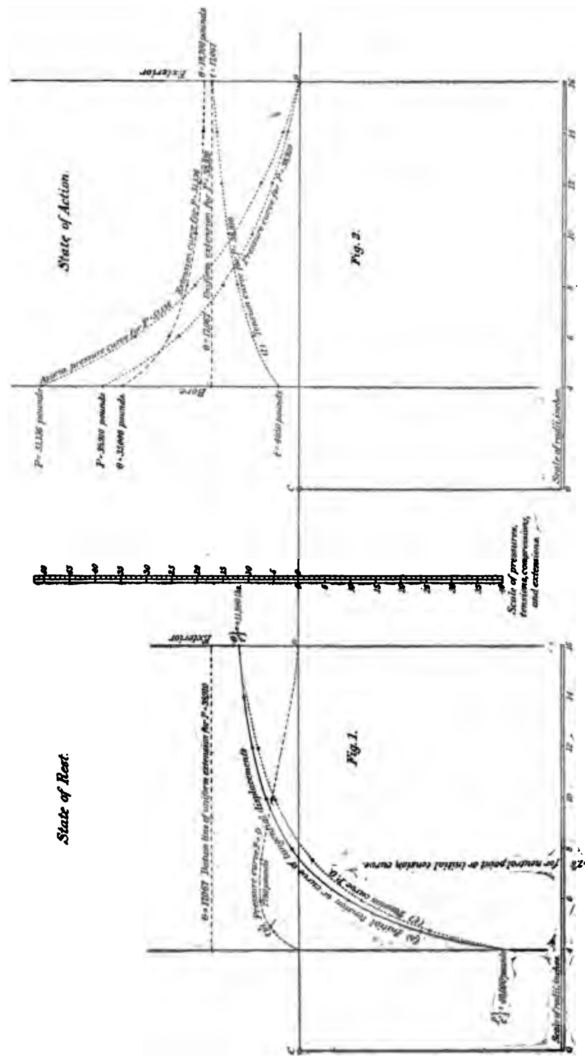
$P=0.682\ (0.001333+0.001166)\ 30{,}000{,}000=51{,}150$ pounds per square inch, which is the same result as will be found deduced in Appendix B. (See Plate IV.)

(*c*) If the steel-cast gun be supposed without initial tension, that is a simple, neutral wall of metal, a becomes equal to zero, and *b*=0.001166 as before, then the elastial tangential resistance will be:

$P=0.682\times 0.001166\times 30{,}000{,}000=23{,}870$ pounds per square inch.

In this case, there being no compression of the bore to start with, the range of dilatation is on the plus side only, and the elastic tangential strength is curtailed accordingly. And in general terms a gun with neutral wall will have only one-half the strength of a

PLATE IV.



Pressures, tensions, and strains in the wall of a gun composed of a single piece, showing the most suitable degree of initial tension. Thickness of wall is equal to one and one-half times the caliber.

built-up wall, or one in which there has otherwise been introduced a proper degree of initial tension.

(*d*) A cast-iron Rodman rifle. For cast-iron E=18,000,000. Although it can not be admitted that there is any certainty in the amount of initial tension produced in a Rodman cast-iron casting, we may assume a most favorable case by taking a=0.001222 and

$b=0.000722$, the relative values corresponding to $\rho=22{,}000$ and $\theta=13{,}000$ pounds per square inch. Then the elastic tangential resistance of this gun would be:

$$P=0.682\ (0.001222+0.000722)\ 18{,}000{,}000=23{,}870 \text{ pounds per square inch,}$$

or the same as the steel-cast gun without initial tension.

These guns are all taken to be $1\frac{1}{2}$ calibers in thickness of wall, and a summary gives—

Relative tangential resistance of homogeneous guns:

(*a*) Built-up forged steel gun, 62,744 pounds per square inch.

(*b*) Steel-cast gun, with proper initial tension, 51,150 pounds per square inch.

(*c*) Steel-cast gun, without initial tension, 23,870 pounds per square inch.

(*d*) Cast-iron Rodman rifle, 23,870 pounds per square inch.

The 12-inch cast-iron rifle recently tested at Sandy Hook has a thickness of wall surrounding the powder chamber equal to $1\frac{1}{2}$ calibers nearly, so that the value of the constant, C, remains equal to 0.682. If now we may be permitted to assume that the initial tension in this gun is represented by the value 15,750 pounds determined from the breech initial tension ring by the very crude and entirely unsatisfactory method of cutting open the ring as a whole. Then

$$a=\tfrac{15750}{18000000}=0.000875,$$

and retaining, as before, $b=0.000722$, the elastic tangential resistance of this gun is represented by:

$$P=0.682\ (0.000875+0.000722)\ 18{,}000{,}000=20{,}607 \text{ pounds per square inch.}$$

It may be said with perfect propriety that this gun has stood a number of rounds with greater pressure than this. So do other guns stand pressures in excess of the calculated, but it is not safe to subject them to such pressures, and we may find in this relative comparison of the strength of guns a very good reason why cast-iron guns are not reliable. They are at every round with full charges momentarily subjected to pressures which exceed a useful limit of strain, and approach the limit of rupture of the metal. The iron having so little extensibility finally shows its failing point in a sudden and disastrous rupture. There can be no good reason given why we should base the strength of a cast-iron gun upon the rupture limit of the metal. The advocates of cast-iron guns do this, but it provides no factor of safety.

We can not apply the preceding rules to the composite guns made with a cast-iron body as the main feature, because of the difference in the moduli of the metals composing the wall; the computation of the strength of these guns requires a more extended application of the formulas. Evidently, however, in the case of the rifled

mortars hooped with steel, the value of the resistance P is much increased over what it would be if the piece were simply cast-iron, because of the much higher modulus of elasticity of the metal of the hoops, which are shrunk on to give their full assistance to the cast-iron in resisting the pressure.

Again, if we take the combined cast iron and steel gun, with a steel tube lining, it is not permissible to assume that the bore of the steel tube can be made to range through the double limit of stretch. For, in the first place, the bore of tube is not compressed to its limit in the state of rest, as in fact the formulas show it to be best to put these tubes in with a play, or at most a very slight shrinkage; and, in the second place, the little extensibility of the cast-iron body in the state of action causes its limit to be reached before the bore of the tube is extended to its limit. Hence, in these guns the limit of dilatation of the bore is curtailed on both sides, and their elastic tangential resistance is considerably below that of the built-up steel gun.

We will now revert to an account of actual operations. The scope of the experiments undertaken to develop knowledge in the construction of built-up guns has already been mentioned, and the results may be summarized. When the making of steel guns and steel forgings for composite guns was authorized in this country there was little known upon the subject of gun steel manufacture, and it was difficult to obtain a correct knowledge of the method of treatment pursued elsewhere. Up to this time the few small gun forgings that had been made in this country had been simply annealed. The scope of existing information is contained in a circular issued April 3, 1883, by the Chief of Ordnance to steel makers in the United States, and afterwards published in his annual report for 1883, page 6 et seq.

The first experiment then undertaken by the Department with the able cooperation of Mr. R. W. Davenport, superintendent of the Midvale Steel Company, was to order three experimental steel hoops of the size required for the guns. These hoops were furnished by the Midvale Steel Company as follows:

One rolled hoop, annealed, oil tempered, and finally annealed

One rolled hoop, annealed simply.

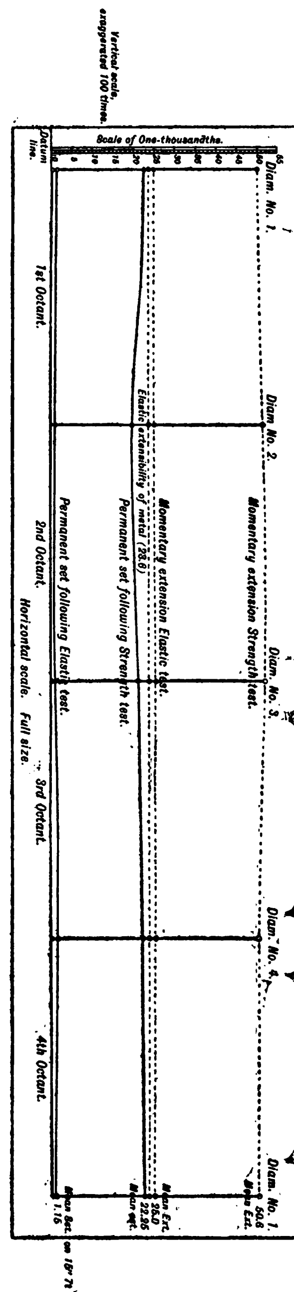
One hammered hoop, annealed, oil tempered, and finally annealed.

The results of the specimen tests and the shrinkage tests[a] were, first, to establish the superiority of the oil-tempered and annealed metal on account of its high elastic limit and great extensibility within that limit; and second, which was not of less importance, to establish a striking similitude between the behavior of the metal in the specimen tests and that of the hoops as a whole in the shrinkage tests. The first of these results was to establish the manufacture of oil-tempered and

[a] See Notes on the Construction of Ordnance, No. 25.

annealed steel for future constructions; the second, which has been repeatedly verified in experiments since made, gave a basis for all future shrinkage work, since it is upon the tests of detached specimens that we must, in general, judge of the physical properties of the metal.

Plate I, made for the hammered hoop, is given as an illustration of these tests. The figures will explain themselves, but we may note that the very slight permanent set of the hoop, 0.00115 of an inch on a diameter of 15.75 inches, following its release from shrinkage in the elastic tests is mainly due to the fact that the hoop in this test was distended beyond the elastic limit of the metal as shown by the specimen tests. The diagram illustrates the great elastic extensibility of steel as a metal and its resilience even when as in the strength test it was distended for hours to nearly double the elastic limit of the metal. The waves of the parts of the circumference of the hoop corresponding to the lines indicate the degree of uniformity of strength in the different several stages of the tests. These lines represent the development of one-half of the interior circumference of the hoop.



[Interior diameter of hoop, 15.75 inches. Thickness of hoop, 2.02 inches.] PLATE I.[a]

The next experiments undertaken were the construction of compound cylinders made to be a complete counterpart of the guns through the reenforce for three different experimental guns under construction, as already mentioned. The purposes of these experimental constructions were fully realized. These purposes were, in general terms: To obtain such data as could be made available in the after construction of the guns; to determine the behavior of the elementary cylinders in combination under the

[a] As here reproduced the scale of the original drawing has been reduced 6½ times.

theoretical shrinkages previously deduced by a mathematical application of the formulas and thus test the theories upon which the formulas are based; to observe the individual behavior of the elementary cylinders; and, finally, to determine whether the shrinkages so deduced should be applied in the after construction of the guns or to what extent they should be modified for that construction. I will here refer especially to the results derived from the construction of the section of the 8-inch built-up steel gun.[a]

Shrinkage tests of hammered and oil-tempered hoop—Midvale No. 9883.

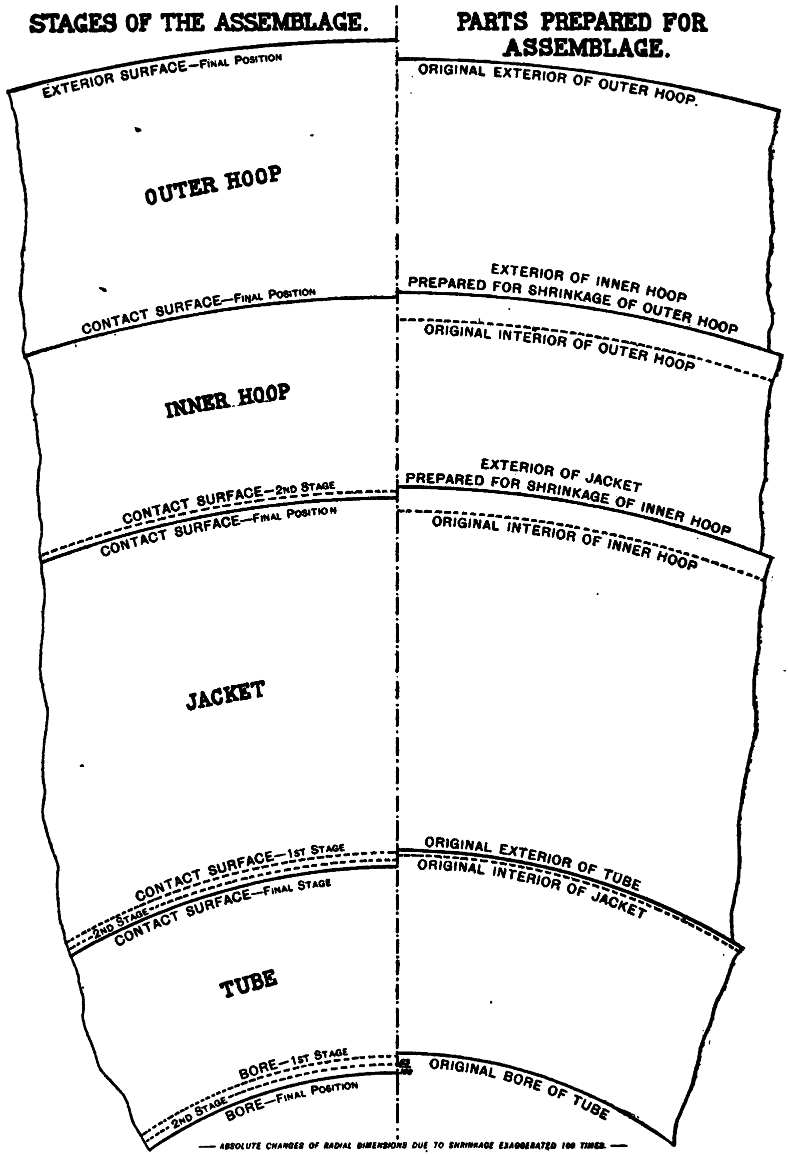
What we may call the "hooping test" in this case, which comprised the successive shrinkages, one upon another of the 4 cylinders composing the section of gun (see Pl. II) and the successive dismantling of these cylinders in inverse order, was accompanied by numerous specimen tests of metal cut from the forgings both before and after their subjection to the hooping test. The several cylinders in the section, viz, tube, jacket, A hoop, and B hoop, were subjected to the same treatment as required in a gun—that is, they were heated and shrunk in place, and when in place were subjected to the same amount of strain that similar parts would have in the built-up gun in what is called the "state of rest"—that is, the normal state. The gun section was left in an assembled condition for several weeks. Under these circumstances a comparison of the specimen tests made before and after the hooping tests showed: The elastic properties of the tube metal under compression were decidedly improved and not materially affected in regard to tensile qualities. The same was observed in regard to the jacket metal which had been subjected to the heat of shrinkage, but the improvement under compression tests was less marked than in the case of the tube. The metal of both hoops showed a loss in tensile qualities varying from 4.85 to 9 per cent, and as a result of these tests it was concluded to give the hoops a margin of 10 per cent on their elastic strength over any anticipated strains in the gun.

In proving the application of the formulas used in deducing the shrinkages the radial changes of dimensions for all the cylinders throughout the section were found to be practically the same as those anticipated; in fact, the results more than fulfilled the best anticipated, but in respect to changes of length in the cylinders the formulas did not give accurate results. The formulas applied in this case were Clavarino's,[b] and it was found that by a modification of these formulas, which consisted in neglecting Clava-

[a] See Notes on the Construction of Ordnance, No. 32.
[b] See Notes on the Construction of Ordnance, Nos. 6 and 7.

rino's assumption that the interior and exterior normal pressures acting upon a gun cylinder do also act upon the ends, as though

PLATE II.[a]



closed. By neglecting this assumption a set of formulas[b] was de-

[a] As here reproduced the scale of the original drawing has been reduced 4⅜ times.

[b] See Notes on the Construction of Ordnance, No. 35.

duced, with which the results of the hooping test gave an almost complete agreement. It must not be inferred from this, however, that Clavarino's formulas are considered unreliable. Their use will probably enable the construction of as well proportioned a gun as any other; but failing cases will be found in their application to special features. A very careful consideration reached from this experiment was that the preliminary specimen tests of the metal of the forgings determine suitable values for the physical constants to be used in the computations; and, second, conjointly with this, the formulas applied can be relied upon to indicate with accuracy the results which will be obtained in practice. That is to say, the formulas are proved correct for the various changes and displacements induced by the pressures produced in shrinking the hoops together; hence they may be relied upon to indicate truthfully what will take place in the augmentation of the same pressures in the state of action.

Plate II, which has been carefully constructed to scale, represents the measured changes of radial dimensions, exaggerated 100 times, which took place in each of the cylinders when they were successively shrunk together in this section. The anticipated compression of the 8-inch bore as deduced by the formulas was 0.0129 of an inch, and its measured compression was 0.0131 of an inch; the anticipated extension of the exterior diameter of the outer hoop—31.5 inches—was 0.0285 of an inch and its actual extension was 0.0276 of an inch, an absolute difference of less than one-thousandth of an inch, and entirely inappreciable when regarded relatively as an extension per inch of hoop diameter or circumference.[a] The degree of accuracy obtained is seen to be 98 per cent of the mathematical result anticipated. I will call particular attention to the actual displacements of metal for the different cylinders in order to emphasize the fact that in a built-up gun the shrinkages are (and can be readily made so) so arranged that the residuum of elastic displacement in each cylinder is sufficient to meet the greatest interior pressure that the gun is computed to withstand; and in addition to this the actual elastic resistance of the built-up forged steel gun is always made much greater than is necessary to withstand the powder pressure obtained in practice. Then it amounts to this—none of the cylinders will be strained nearly to the elastic limit by the powder pressure. Referring to Plate II, the maximum strains in the several cylinders stand in relation to the elastic properties of the metal as follows:

Bore of tube *compressed* to 100 per cent of elastic limit.

Interior surface of jacket *compressed* to 20 per cent of elastic limit.

Interior surface of A hoop *extended* to 63 per cent of elastic limit.

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[a] See Notes on the Construction of Ordnance, No. 32, p. 20.

Interior surface of B hoop *extended* to 65 per cent of elastic limit.

Now, when the interior pressure—which for this state of the system is *nil*—is introduced, the bore of the tube has double its range of elastic displacement to go through before the outer limit is reached, the interior of jacket passes from a negative to a very moderate positive extension value, and the two hoops undergo a further extension within the margin of elastic strength left in them—their displacement being relatively small in comparison with that of the bore of the tube because of their remoteness from the action of the central force. A confirmation of these experimental results is shown in the drawing (Plate III) made to represent the principal features of the construction of an 8-inch rifle.[a] Lines are drawn to represent the measured compression of the bore of tube due to the shrinkage of the several series or layers of outer cylinders.[b] The line of final compression is seen to be in close proximity to that representing the anticipated compression, the slight excess of the actual over and anticipated compression being accounted for by the fact that the tube actually used in this gun was a somewhat more yielding one than that for which the shrinkages were computed. If we estimate this excess, however, for the only part of the bore designed to be compressed to the full limit—that is, for the powder chamber—we find the excess of compression to be but 1 per cent more than the anticipated. With such results obtained with a gun weighing 13 tons and involving so many shrinkage surfaces, is it not safe for one who has seen this done to claim that the production of the proper degree of tensions in a built-up gun is a *certain* process which, after the plans of the gun are made, requires only competent workmen, good machines, and requisite care in inspection to effect its accomplishment? Lieutenant Howard's report[c] upon the construction of a number of 3.2-inch field guns at the West Point Foundry (where also the 8-inch rifle was put together) shows by the coincidence between the anticipated and the actual tensions obtained in these guns, which contain only one shrinkage surface, that the construction is not only practicable, but its results are sure. A single shrinkage surface makes the anticipated result more difficult of accomplishment, because if there be two or more such surfaces any error, except what might occur from actual carelessness on the part of the workmen and inspector, due to finishing the work for a preceding surface, can be corrected in the next shrinkage applied.

The experiments made to determine the effect of a high heat upon oil-tempered steel exposed to its action for a short time

[a] The vertical scale of relative compression is actually exaggerated about 100 times only, instead of 1,000 times, as written on the drawing.

[b] See Report of the Chief of Ordnance, U. S. Army, 1886, p. 229.

[c] Appendix Report of the Chief of Ordnance, U. S. Army, 1887.

showed, in one case, that the physical properties of a short section of an 8-inch tube were not materially affected by pouring a quantity of molten iron into a mold surrounding the steel piece and leaving the iron in contact with the outside of the steel for three and five-tenths minutes. In another case the quality of the metal in a short cylinder of Whitworth gun steel was not injured by the white heat of a furnace applied a sufficient length of time to raise a part of the outer surface of the piece to a dull red heat. In this instance the steel cylinder was shrunk upon a core—one end and the outer surface only being exposed directly to the heat. The utility of these experiments is found in the necessity which sometimes, though rarely, arises to remove a hoop or other cylinder after it has been shrunk in place; indeed the whole gun can be dismantled in this way if necessary. Pouring molten cast-iron around the piece to be removed has been found to be the most practicable method. The pieces thus removed can be used again, as it is known that the quality of the metal is not materially affected when the operation is skillfully performed.

The experiments[a] to determine the amount of frictional resistance to the sliding of one cylinder over another when shrunk together, in the usual way, were made with special reference to determining what would be the aggregate hold of the jacket shrunk upon the tube in a gun due to this source of resistance alone. That is, to determine what resistance the friction between the two surfaces would offer to any longitudinal displacement of the tube in the jacket. The tests were made with special reference to the plan of pin coupling shown in the drawing (Plate III). The four pins put in near the muzzle end of the jacket would offer an aggregate resistance of about 1,131,300 pounds to shearing, but this being only about one-third of the total effort (3,189,700 pounds) which would be exerted to separate the tube and jacket longitudinally for a pressure of 45,000 pounds per square inch on the breechblock, it was necessary to depend upon the frictional resistance for material assistance, and hence it was expedient to test the value of this frictional resistance.

Several hoops, three and four inches in width, were carefully prepared and shrunk upon a piece of gun tube. The pressure which each exerted upon the tube was determined by the usual formulas and noting the effect of the shrinkage. These hoops were pushed off in the testing machine at Watertown Arsenal. From the force required to start and keep these hoops moving under pressure it was found that the frictional resistance somewhat exceeds 15 per cent of the normal pressure at the contact surface of two steel

[a] Report of the Chief of Ordnance, U. S. Army, 1885, pp. 317 and 321.

cylinders shrunk together as in gun construction. In the gun shown in the drawing (Plate III) the least pressure at any time (i. e., in the state of rest) existing at the contact surface between the tube and jacket is 7.17 tons per square inch, as computed by Clavarino's formulas. The area of the surface of contact between the two pieces is 3,816 square inches, making the aggregate normal pressure about 62,785,000. Taking, for safety, only 10 per cent of this, instead of 15 per cent, we have over 6,000,000 pounds resistance to sliding due to the friction alone. And as the force tending to slide the pieces is scarcely more than one-half of this, it may be concluded that the resistance to longitudinal separation of the parts of this gun is amply provided for, the pins being in the nature of a security against any start taking place.

In 1885, an 8-inch forged steel trunnion hooped was procured from the Midvale Steel Company. It was the first forged hoop of this character—for seacoast guns—to be made in this country, and as it was known that the manufacture would present special difficulties, it was determined to make the first an experimental piece—that is, for thorough specimen and shrinkage tests, to determine the quality and uniformity of the metal to be obtained in a forging of that size and character. This forging was treated in the usual way by oil tempering and annealing. The results[a] of the tests showed an excellent, uniform quality of metal throughout the piece, and incidentally demonstrated a thoroughly good effect of the oil tempering and annealing treatment in a thick and irregular forging.

The gun shown in the drawing (Plate III) was first tested in the condition there shown—that is, without chase hooping to the muzzle. Since then, however, the piece has been hooped quite to the muzzle. In the first state, after firing 24 rounds, the bore of the tube at some 15 inches from the muzzle was found to have enlarged 0.006 of an inch. The enlargement, although small in reality, was considered sufficiently serious to conclude that it would be best to put on the chase hoops, a matter which had been discussed for the original construction. This tube had been received from Whitworth & Co., and it was not certainly known what method of treatment the steel had received—that is, whether it had been carefully annealed after oil tempering. The indications of the firing test pointed to a zone of compressed metal near the exterior surface, probably due to lack of annealing after oil tempering. Such a condition would, as we have already discussed, tend to weaken the tube to support an interior pressure. Then, although the gun steel procured from home manufacturers was known to be in all cases carefully annealed as a final operation in manufacture, experiments were undertaken to analyze the condition of strains left in a piece on the one hand when oil

[a] Notes on the Construction of Ordnance, No. 39.

tempered as a final operation, and on the other when annealed after the oil tempering. The method of examination pursued[a] was that already indicated as proper in examining into the conditions of initial strains existing in a Rodman casting. The results, in brief, were that the pieces of tubes which were annealed as a final operation were almost entirely free from internal strains, while the one which was oil tempered, and not annealed, exhibited a state of compression over its entire surface metal, exterior, bore, and ends, while the interior of the mass was in a state of tension.[b] It may be well here to contradict an impression held by some that the after annealing of the gun steel removes all the beneficial effect of the oil tempering. This opinion would not be held by anyone made conversant with the facts in the case, as have been demonstrated by numerous tests made with steel of home manufacture. This question has been pretty thoroughly treated in the discusion before the Naval Institute in January of this year.[c]

The first of the new steel field guns—3.2-inch caliber—was made of steel simply annealed. It has an excellent record for endurance, but at the end of 100 rounds the bore showed an enlargement of 0.009 of an inch at the bottom, thence gradually diminishing to 0.001 of an inch at the muzzle. All subsequent forgings made for these guns have been oil tempered and annealed. In order to test the comparative merits of the two methods of treatment, 100 rounds were recently fired from a new gun at Sandy Hook, with the result that there was no appreciable enlargement of the bore, except a slight enlargement near the seat of the shot.[d]

Three and two-tenths inch breech-loading field guns, steel.—The first of these guns[e] was made at the Watertown Arsenal in 1884, after designs prepared by the Ordnance Board. The piece consists of a tube covered in one layer by a jacket, trunnion hoop, sleeve, and key ring. All of these parts are made of forged, oil tempered, and annealed steel, and the outer layer, except the key ring, is assembled by shrinkage on the tube. The jacket projects to the rear of the base of the tube, and is threaded within the recess to receive the base ring, which holds within it the slotted-screw breechblock. The trunnion

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[a] See Notes on the Construction of Ordnance, No. 41.

[b] This last condition of affairs was actually found to exist to some extent in the 8-inch gun tube. When the outside of the chase was turned to prepare for hooping to the muzzle the bore of the tube contracted as the metal was turned off, which plainly indicated that there existed a zone of compressed metal at the exterior of the tube. Now becomes apparent the utility of hooping, for a proper degree of shrinkage having been computed for the muzzle hooping, the application of the hoops put this part of the tube into the desired state of initial tension, and all the firing since then has not enlarged he bore at all.

[c] Proceedings of the U. S. Naval Institute—steel for heavy guns No. 40, p. 62.

[d] Appendix 39, Report of the Chief of Ordnance, 1887.

[e] Report of the Chief of Ordnance, 1884, p. 509.

hoop is connected with the jacket in shrinkage by a lap joint; the sleeve abuts against the trunnion hoop and the key ring, which is screwed on cold—the male thread being cut on the tube—fits close against the muzzle end of the sleeve. The breech mechanism can be adapted to use either the Davis gas check or the Freyre, the latter being a steel ring of triangular section at the side, with a thin front rim or edge, which is forced outward to seal the escape of gas by a conical forcing head on the spindle. Both descriptions of gas check have been fired many rounds at Sandy Hook, and both have given satisfaction.

The piece weighs 800 pounds, and has a length of bore equal to 26 calibers. The first gun made has been fired over 2,400 rounds and is still serviceable; and several of the 25 guns recently finished have been fired from 100 to 200 rounds, their endurance being entirely satisfactory. The charge of hexagonal powder used with the Freyre gas check is 3.75, and with the Davis 3.5 pounds; the weight of projectile is 13 pounds. For muzzle velocity the 3.75 charge has given 1,749 feet and the 3.5-pound charge 1,686. A range of 6,479 yards, or 3.75 miles, with a mean deflection of 95.6 yards to the right, is given with 20° elevation. The mean deviation given at 1-mile range is about 3 feet. Taking an average of some 900 rounds, the rapidity of fire obtained has been about 70 rounds per hour—the maximum being 46 rounds in twenty-six minutes, or at the rate of 120 rounds per hour. The type gun of this caliber has been tested and accepted by the Board for Testing Rifled Cannon. This board continued the test of the gun up to an endurance of 1,800 rounds. The data given above is taken from the results of trials made by the testing board.

The 5-inch breech-loading siege rifle and 7-inch breech-loading rifled howitzer were both made at the Watertown Arsenal under the direction of Lieut. Col. F. H. Parker. Both guns are after designs made by the Ordnance Board. In general plan of construction both guns, and more especially the 5-inch siege rifle, are nearly a counterpart on a larger scale of the 3.2-inch field gun. The forgings for the rifle were made by the Midvale Steel Company. The weight of piece is 3,500 pounds, and the length of bore 30 calibers. It is fitted with the slotted-screw breech mechanism and Davis gas check. The details of design of 7-inch howitzer were worked up by the late Lieut. William Medcalfe. The piece is designed to give 6,000 yards range to a shell weighing 105 pounds. The length of bore is 12 calibers, nearly, and weight of piece 3,750 pounds. The forgings for this piece were made by the Cambria Steel Works and fully meet the high standard of quality prescribed by the Ordnance Department.

Eight-inch breech-loading rifle, steel.—The manufacture of this gun was completed at the West Point Foundry in June, 1886. The tube,

jacket, and trunnion hoop forgings were procured from Sir Joseph Whitworth & Co., and the remaining forgings for hoops and breech mechanism from the Midvale Steel Company. The manufacture of the gun was long delayed by the nondelivery of the forgings from Whitworth, which were not finally received until February, 1885. The general construction of the gun will be sufficiently explained by the drawing (Pl. III), except the breech mechanism, which is of the slotted-screw system.[a]

The elastic resistance which this gun will offer to interior pressure is 56,000 pounds per square inch. It has, in firing with experimental powders, been several times subjected to pressures of over 40,000 pounds, and two of the records show 44,500 and 46,300 pounds, but the usual pressure will not exceed 36,000 or 37,000 pounds. In any event, for pressures likely to be obtained in service, the gun has a large margin of elastic resistance. Up to this time the gun has been fired 101 times, with the following charges: Two rounds with a powder charge of 65 pounds; 12 of 85 pounds; 3 of 95 pounds, and 84 of from 100 to 113 pounds weight. The weights of projectiles were: In 7 rounds, 182 pounds; in 4, 235 pounds; in 1, 250 pounds, and in 89, from 285 to 302 pounds. At the one hundred and first round a range of 10,698 yards, or a little over 6 miles, was obtained with a charge of 95 pounds of powder and 289-pound projectile. The muzzle velocity for this charge was 1,800 f. s., or about 75 f. s. less than would have been obtained with a full charge of suitable powder.

The accuracy of the piece is remarkable. Of five shots following one sighting shot, fired at a target—range 3,000 yards—all were placed within a circle of 6 feet diameter.

The following are some of the results obtained in the firing tests of this gun in which a number of different experimental powders have been used:

Round.	Powder charge.		Projectile weight.	Density of loading.	velocity per second.	Pressure per square inch.	Muzzle energy.
	Kind.	Weight.					
		Pounds.	*Pounds.*			*Pounds.*	*Foot-tons.*
5	German	100	182		2,144	29,500	
6	do	100	235		1,942	32,150	
10	Du Pont, P. A	100	235		1,938	32,950	
24	Du Pont, P. K	100	235		2,026	37,660	
31	Du Pont, P. N	110	289	0.98	1,878	36,000	7,066
37	German	110	289	0.98	1,875	35,900	7,043
43	do	110	302	0.98	1,857	37,000	7,219
58	Du Pont, Q. M	113	300	1.00	1,852	37,640	7,133
64	Du Pont, Q. U	110	300	0.98	1,877	40,700	7,333
73	Du Pont, Q. Y	105	289	0.935	1,904		7,263
80	Du Pont, Q. W. A	105	289	0.935	1,879	36,500	7,073
97	Du Pont, P. N. A	113	301	1.0	1,852	35,500	7,157

[a] A full description of the details attending the manufacture of this gun is given in a report made by the writer. (See Report of the Chief of Ordnance, U. S. Army, 1886, p. 229.)

The results obtained with the last samples of powder tried indicate that the muzzle energy of the gun can be placed at 7,200 foot-tons, obtained with a shot 3½ calibers in length, weighing 300 pounds, and without exceeding a pressure of 37,000 pounds.

WORK DONE BY THE NAVY DEPARTMENT.

The brief outline that can be given of the work of the Navy Bureau of Ordnance will be devoted principally to showing the remarkable progress that has been made by the Navy in the production of built-up forged steel guns, and that the question whether this gun shall be the established type of construction in this country is no longer an open one. Not only is the type of gun established, but the home manufacture of the forgings also.

The Midvale Steel Company, which is amply able to fill the orders undertaken, has supplied, or is now under contract to supply, the following complete sets of steel gun forgings, as given in Appendix A, viz, 15 sets for 3-inch breech-loading boat howitzer, delivered; 2 sets for 5-inch breech-loading rifles, delivered; 52 sets for 6-inch breech-loading rifles, of which 20 sets have been delivered.

The recent contract made by the Navy with the Bethlehem Iron Company provides for the delivery of about 1,225 tons of steel gun forgings for 6, 8, 10, and 12 inch calibers. Summarizing the whole number of sets of forgings, procured or under contract for delivery, by home manufacturers for the Navy; there are 148 sets, viz, 15 3-inch, 2 5-inch, 101 6-inch, 4 8-inch, 24 10-inch, and 2 12-inch: To get at the whole number of guns made, or now provided for in the Navy, there must be added to the above list 8 8-inch and 3 10-inch rifles for which the forgings were mainly procured from Charles Cammell & Co., and Whitworth in England. This makes a total of 159 steel rifles, of which 141 are built-up forged-steel guns of 6-inch caliber and upward.

The first built-up forged-steel gun, which was also the first of its kind made in this country, was an experimental 6-inch breech-loading rifle. A contract was made for this gun by the Navy Bureau of Ordnance with the South Boston Iron Works, January 5, 1880, the Company to furnish the steel. The tube, of annealed metal, was obtained from the Nashua Steel Company, but the jacket was supplied by Firth, of oil-tempered steel. The two guns following were also 6-inch, of annealed metal, the forgings for which were procured from the Midvale Steel Company, under orders dated in May and June, 1882. Beginning with 1883, the Midvale Steel Company have delivered or contracted for 52 sets of annealed and oil tempered and annealed forgings for 6-inch guns. The forgings to be delivered under the contract made with the Bethlehem Iron Company are also

to be annealed, oil tempered and annealed, and it is stipulated that the company shall begin the delivery of the 6-inch forgings August 1, 1888.

Since the commencement of the active work allowed by appropriations in 1883 and subsequent years, the Navy Bureau of Ordnance has procured the forgings for and has completed, or nearly so, 21 6-inch rifles, 8 8-inch rifles, and 2 10-inch. Work on a third 10-inch rifle, to be 34 calibers in length of bore, has been commenced with forgings now at the Washington Navy-Yard.

Of these guns the West Point Foundry contracted for the manufacture of 5 6-inch and 2 8-inch rifles. Four of the 6-inch are completed, and the three remaining guns are in the final stage of construction. The South Boston Iron Company contracted for the manufacture of 6 6-inch and 2 8-inch rifles. Five of the 6-inch are completed, and the 2 8-inch are to be completed in March, 1888.

The Washington Navy-Yard has completed 2 5-inch, 10 6-inch, 4 8-inch, and 1 10-inch rifles, and has another 10-inch about three-fourths completed. Carriages for all the guns have also been made there, besides a number of 3-inch guns and projectile work.

This much has been accomplished since 1883, notwithstanding the considerable delays made by waiting for the first deliveries of the forgings and the lack of machinery and plant for the new and superior quality of work demanded. At present the Washington Navy-Yard has worked up its plant to a capacity for a yearly product of 25 6-inch and 10 8-inch guns and carriages, etc., or a proportionate amount of work on other guns. Plans are now in process of development which will make the yearly capacity of the yard equal to completing 25 6-inch, 4 8-inch, 6 10-inch, and 4 12-inch rifles or a proportionate number of any given calibers.

The finished guns have been subjected to the proof required by law, which constitutes a series of 10 rounds fired with all possible dispatch, and a number besides have been subjected to additional firings at the proving ground at Annapolis and in firing practice on shipboard.

All are officially reported to have withstood the firing tests perfectly and to give satisfaction in service. One 6-inch gun has been fired about 300 times, and in the Report of the Secretary of the Navy for 1885 it is stated that 6-inch gun No. 4 had been fired 57 rounds and one 5-inch gun 26 rounds. In the rapid-firing tests the 6-inch rifle was fired 10 rounds in eleven minutes, and the 8-inch 10 rounds in fifteen minutes, although one of the shots was accidentally dropped in this last trial and occasioned a delay.

In their main features the Navy and the Army steel guns are alike, the most important difference in construction being that in the navy guns the trunnion hoops are made of oil-tempered and annealed castings and are screwed on cold, while in the Army gun designs

these hoops are forged and assembled by shrinkage. In the matter of charges, also, the practices differ, in that the rule in the Navy is to use a charge of powder equal to about one-half the weight of the shot, while in the Army the weight of projectile is made proportionately much heavier. The lighter projectile gives a high velocity with a relatively flat trajectory, which is best adapted, as it is claimed, to the conditions of naval combat. The range given for the experimental 6-inch gun is 3,046 yards at 3° 10′ elevation and 7,000 yards at 10° 10′ elevation.

The weights of the present type guns which have 30 calibers length of bore and are hooped to the muzzle, are: 6-inch, 10,942 pounds; 8-inch, 28,077 pounds; and 10-inch, 57,485 pounds.

The charge determined for the 6-inch is 53 pounds 4 ounces of German or 48 pounds 2 ounces of Du Pont's brown prismatic powder, and 100-pound projectile; and for the 8-inch 122 pounds of German or 112 pounds of Du Pont's American powder, with 250-pound projectile. It is stated that the American brown powder gives the same muzzle velocity as the German with less pressure.

The velocities and pressures realized in the several types of guns reported in 1886–87 (Report of the Secretary of the Navy) are:

Date.	Gun.	Powder charge.		Projectile weight.	Muzzle velocity, per second.	Pressure.
		Kind.	Weight.			
			Pounds.	*Pounds.*	*Feet.*	*Tons.*
1887...	5-inch	American	30.5	60	2,011	14.2
1886...	6-inch	.....do........................	54.0	100	2,105	15.6
1886...	8-inch	German	....	....	2,013	15.5
1887...	8-inch	American	113.0	250	2,008	15.5

I do not know that it will be necessary to add to the proofs already given of the success of the system of built-up forged steel guns as already achieved in this country. The objections which have been raised to the adoption of the system do not appear to have any force under present circumstances.

There is certainly no mechanical difficulty in making these guns which can not be overcome by the exercise of proper care in manufacture. The machining of the finished surfaces requires less care, for instance, than is exercised in making paper rolls in this country, for which a series of rolls several feet in length must be finished so true that when piled one on top of the other no ray of light must pass between them. A variation of 0.003 of an inch is usually allowed in turning the shrinkage surfaces for a gun, which allows any skilled workman, with even a fairly good machine, to accomplish the desired result with ease, a fact which any one can ascertain for himself by consulting the workmen at the West Point Foundry, or any other shop where nicety of workmanship is required. Again,

the shrinkages required to procure the maximum resistance of a gun built up of several layers are susceptible of interchange; that is, a certain aggregate effect is required which may be had by a relatively heavy shrinkage of the first layer and a relatively light shrinkage for the second layer, and so on, or the reverse. Measurements taken of the bore after the first layer is applied give an accurate check upon the result, and it is then easy to modify the shrinkage for the application of the next layer if necessary. The question of making a thoroughly good built-up gun of forged and oil-tempered steel is practically a question of skilled workmanship only, and all the allowances which are permitted in the accuracy of finish for the work render it not only entirely practicable but comparatively easy of accomplishment.

The division of the gun into many parts has all the advantage of procuring the very best of material, because of the thorough working which each part receives and the facility for examination of the quality of the material which is afforded. In the construction of the gun these different parts are assembled to give a great economy of material. The jacket affords all the requisite longitudinal strength and also a due share in assisting the tube and hoops for tangential resistance. The hoops are needed for the tangential and not for longitudinal strength, and the methods pursued in their manufacture and application in the gun structure essentially fit them to afford the kind of resistance required of them.

It has also been objected that the heat and strains due to firing would disturb the adjustment of the tensions of the several parts. The best answer to this, of course, is that practice has proved the contrary. Again, Gadaud mentions cases of hoops that were removed from guns after long service—yet resumed practically their original dimensions. When the gun is fired the heat is by no means confined to the tube, but extends through the gun, so that the distention due to the heat is felt throughout the wall; but the heat due to firing does not affect the strength of the metal, and the distention produced by the heat is not an added strain, so that an equilibrium is established between the force of the interior pressure and the resistance of the gun with strains upon the metal due to this force which scarcely exceed those occurring in the cold state. The tube in a built-up gun is subjected to the greatest strains in the structure, and there is always left a large margin of elastic strength in the outside parts. And supposing the tube to be heated in excess, this effect would simply be equivalent to a case of a gun assembled with a greater shrinkage. Then, in firing, the place of most dangerous strain in the gun—that is, at the surface of the bore of the tube—would be under a less instead of a greater strain. The principal objection has been the idea that the introduction of the manufacture

would require so long a time as to make it expedient at least to adopt some temporary system of gun construction for immediate use in case of necessity. But this matter has now been neglected so long in regard to the legislation needed for the making of guns for the land service that at present the manufacturing facilities for making the built-up guns are quite as complete as those for making any other kind of guns; hence there is no reason on this score why we should not at once proceed to manufacture the best gun.

COMMERCIAL ADVANTAGES OF GUN AND ARMOR FORGING PLANT.

The great necessity for purity and strength of material required in the steel to be produced for war purposes will, as indeed it has already done, give a rapid advancement in knowledge of how best to treat the metal in order to get the best results in steel forgings of every nature required for commercial purposes.

The substantial interests that will accrue to the commerce of the country by the demand for guns and armor of home production are manifold. We have good authority for the statement that the United States is metallurgically independent as to its iron ores, iron, and steel, but it is economically at a disadvantage in point of cost of material and labor. This disadvantage works against the growth of large forging or press plants, and also against the production of the best grades of steel required for many commercial purposes. If the Government will demand guns and armor of home or domestic manufacture, it will enable our own steel makers to produce the heavier forgings required for shipbuilding and other structural purposes to compete with the foreign importations of such material now made, to increase the demand for it in the United States, and to compete with foreigners for the trade of neighboring countries. In other ways, also, the scientific investigations connected with the manufacture of steel and its appliances for war purposes will assist the commercial interests of the country.

The gun plant can be applied to make the best of steel for either the purposes of war or commerce, as has been proven in the experience of both the establishments that have up to this time furnished gun forgings to the Government. The manager of one of these steel works states:

Undoubtedly this experience has been of very great advantage to us in teaching what the best molecular condition of the metal is, and we take advantage of the plant erected for the ordnance work in our regular trade work to give our customers the very best product and also to change or improve the physical qualities of our commercial products to meet the demands of customers. If a customer wants material in the very best possible condition, we use the processes for ordnance metal; and in meeting the demand for the very high grade metal required for ordnance our studies have caused constant improvements and shown us *how* to improve our regular product.

The force of this will be understood in mentioning an instance where the ingots made for a lot of gun hoops in the first order undertaken by a company did not meet the ordnance requirements and called forth the statement by officers of the company that it would be necessary for them to learn over again "what constitutes sound steel;" and the next lot of ingots, produced by pursuing a different method of manufacture, fully met the requirements. The method of improving the quality of car axles by treating by the so-called water-tempering process at the Cambria Iron Works is very largely due to the care and research made by the capable officers of that company in studying the manufacture of ordnance metal.[a] If it be true, as has been recently stated, that there is a present tendency to return to wrought iron for boiler plates and axles, the reason can only lie in a careless treatment of the steel manufactured for such purposes, and it will behoove the steel makers and mechanical engineers to learn generally, what many of them do already know, that it is not true even of mild steel that "it can be badly worked and maltreated with impunity, yet it can be trusted under all circumstances."[b]

The shrinkage tests of steel hoops (already mentioned) made in connection with gun work, and the formulas applicable to the shrinkages used in guns, already established to be so accurately consistent with good practice, can be profitably studied in connection with the application of hoops or rings for strengthening purposes generally, as used in commerce. In general, if only a single hoop or row be applied it will be sufficient to give a shrinkage somewhat within the elastic stretch of the metal of the hoop to prevent an overstrain. In the case of locomotive and car wheel tires it appears that the following shrinkages are in use or recommended: By Krupp, one one-hundredth of an inch per foot of interior tire diameter; Pennsylvania Railroad Company, one-eightieth of an inch per foot of interior tire diameter; Midvale Steel Company, one one-hundredth of an inch per foot of interior tire diameter.

These rules give (neglecting the compression of the wheel due to the pressure of the tire) an elongation of 0.833 or 1.04 thousandths per linear inch of interior tire diameter (or circumference). They observe the same care with regard to keeping the tension of the metal within its elastic stretch as is done in making built-up guns. And the tires on locomotive and car wheels are constantly subjected to the worst sort of vibratory action, yet they hold their place for long periods of time. It may be remarked, however, that when as in the ordnance metal one has a steel possessing (for hoops) from 1.75 to

[a] Steel Car Axles, by John Coffin. Phila. Amer. Soc. of Mech. Eng., Nov., 1887.

[b] Edward Bates Dorsey, C. E. Paper read before the U. S. Naval Institute, Jan. 5, 1887.

2.0 thousandths elastic stretch, the shrinkage of a strengthening ring might well be made as great as 1.5 thousandths per linear inch of interior diameter or between one-fiftieth and one-sixtieth of an inch per foot, and this would presuppose a highly resistant interior body, such, for instance, as the case of a ring shrunk upon a solid shaft. With a hollow interior body where an overcompression from the ring might be feared, it would of course be necessary to use a proper thickness of ring. Economy of metal for the strength required would always be obtained by using the highly elastic and strong ordnance metal with the greater degree of shrinkage to which it is adapted.

To cite an actual case of a hammer used for forging: The hammer head of steel is held in place by being shrunk on the end of the bar. It had been assembled with a shrinkage of five sixty-fourths of an inch on 19½ inches diameter; with this shrinkage the socket of the head broke or cracked under usage. The shrinkage was then reduced to three sixty-fourths of an inch, but the results were still unsatisfactory and the head was found to stretch and work loose. The attention of the management then having been drawn to the shrinkage tests of the gun hoops, the results were applied to the case of the hammer head and a shrinkage of three one hundred and twenty-eighths of an inch determined upon. This value gives a stretch not to exceed 1.2 thousandths per linear inch of socket diameter. After this, when the bar broke at one time and was removed the socket of the head resumed its original diameter. Since the last application with the proper shrinkage (three one hundred and twenty-eighths) the hammer has been in constant use for about eighteen months and no trouble has been experienced and no movement of the head has taken place.

Mr. Morgan, of the Cambria Works, states that pieces of gun steel rejected in the forgings made for that purpose can be worked down to small sizes for commercial uses, and from the excellence of the stock and its thorough working will bring the highest market prices.[a] Certainly also there would not be a total waste of any rejected piece of forging, since it could always be handled by the plant at hand, and, as a last resort, heated and cut up under the hammer for remelting. Supposing that steel-cast guns were in vogue, any rejected casting of large size would be a total waste, as there would be, presumably, no hammer plant at hand of sufficient size to handle or break it up. The large castings for steel-cast guns might be cut up in lathes to dimensions sufficient to break up under light hammers, but the cost of this operation would probably preclude

[a] Our Coast Defense, its Cost and its Mechanical Problems, by Jos. Morgan, jr., Amer. Soc. of Mech. Eng., fifteenth meeting. Washington, 1887.

its adoption. Finally, on this subject, the establishment of several gun and armor forging plants will place the country in a position to be independent of foreign products for its supply of such war material—a position demanded in time of peace and absolutely essential in time of war.

THE PNEUMATIC DYNAMITE TORPEDO GUN.[b]

The pneumatic dynamite gun which has recently been brought forward promises to serve an important place as an adjunct to other means of torpedo defense and long-range armor piercing guns in any system of harbor defense that may be adopted. The possibilities of its use in naval warfare, especially on board of harbor defense vessels, in which, probably, its greatest scope of usefulness will be found, need not be more than mentioned here. But if the present promise of the gun is borne out in extended application to suit the varied conditions of service, it will become a necessity for the land defense, and should be used as a gun of position forming part of the shore armament. The trials which have been made with an 8-inch gun of this caliber, at Fort Lafayette, have demonstrated the fact that charges of 55 pounds of explosive gelatin and dynamite can be thrown to a distance of about 1,800 yards, with a striking degree of accuracy, the total weight of projectile in this case being 136¼ pounds. The same gun, according to the report of the naval board which witnessed trials with the gun in March, 1887, gave a range of 3,868 yards or 2.2 miles with a projectile weighing 139½ pounds.

The great advantage of this gun appears to lie in its ability to throw large charges of high explosives with entire safety, using compressed air as a propulsive force, which may be exploded with destructive effect upon the deck of a hostile ship, or with even greater effect by means of the salt-water fuze used with the projectile beneath the water under or near the ship.

The pneumatic gun can not be considered a simple contrivance, nor will the establishment of a number of them in our seacoast forts, if such a state of affairs is reached, be an inexpensive matter. Its success so far, however, is certainly encouraging and has warranted the recommendation of the Chief of Ordnance to purchase a gun of the class for trial.

The range of modern heavy guns from shipboard is from 7 to 8 miles, and it is an absolute necessity for any properly arranged system of seacoast or harbor defense that such guns should be met by a number of equally effective guns from shore.

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[b] See Journal of the Military Service Institution, June, 1887, vol. 8, No. 30, p. 169.

APPENDIX A.

List of the principal steel forgings already procured or under contract for delivery in the United States for the Army and Navy from the Midvale Steel Company and Cambria Iron Works.

Service.	Name of manufactory.	Date of order.	Number and character of forgings.	Approximate aggregate weight.	Treatment.	Remarks.
				Tons.		
Army	Midvale Steel Co	Sept. 20, 1883	15 rolled hoops for 12″ C. I. hooped, M. L. M	5	Oil tempered and annealed	Delivered.
Navy	do	Oct. 6, 1883	8 sets of forgings for 6″ B. L. R	50	Oil tempered and annealed; T hoops, oil tempered and annealed castings.	Do.
Do	do	do	2 sets of forgings for 5″ B. L. R	12	do	Do.
Army	do	Nov. 1, 1883	23 rolled and 13 hammered hoops for 8″ B. L. R	8	Oil tempered and annealed	Do.
Do	do	May 21, 1884	27 rolled hoops for 12″ C. I. hooped and tubed B. L. R.	16	do	Do.
Navy	do	June 20, 1884	12 sets of forgings for 6″ B. L. R	67	Oil tempered and annealed; T hoops, oil tempered and annealed castings.	Do.
Army	do	Nov. 21, 1884	50 tubes, breech cups, and muzzle collars for converting 10″ S. B. Rodman guns in 8″ M. L. R	80	Oil tempered and annealed. Muzzle collars not treated.	Do.
Do	do	Apr. 20, 1885	25 sets of forgings for 3″.2 B. L. R	17	Oil tempered and annealed	Do.
Do	do	do	Tube, jacket and T-hoop forgings for 8″ B. L. R	9	do	Do.
Do	do	Sept. 11, 1885	1 set of forgings for 5″ B. L. R. (siege)	4	do	Do.
Do	Cambria Iron Works	Sept. 15, 1885	20 forged hoops for 10″ B. L. R	15	do	Do.
Navy	Midvale Steel Co	Dec. 31, 1885	40 hoops for 8″ and 10″ B. L. R	16	do	Do.
Army	do	June 11, 1886	12 rolled hoops and 1 forged trunnion hoop for 12″ C. I. hooped B. L. M.	6	do	Do.
Do	Cambria Iron Works	June 22, 1886	1 set of forgings for 7″ B. L. H	2	do	Do.
Do	Midvale Steel Co	Sept. 16, 1886	18 forged hoops for 8″ B. L. R	8	do	Do.
Do	do	Feb. 19, 1887	25 sets of forgings for 3″.2 B. L	15	do	Delivery nearly completed.
Navy	do	July 28, 1887	10 sets of forgings for 6″ B. L. R	55	Oil tempered and annealed; T hoops, oil tempered and annealed castings.	Under contract for delivery.
Do	do	Nov. 16, 1887	22 sets of forgings for 6″ B. L. R	120	do	Do.
Army and Navy.	do	Various	Forgings, miscellaneous hoops, breech mechanism parts, projectiles, shafts, and T hoops, castings for projectiles, gun-carriage fittings, and trunnion hoops.	70	Forgings oil tempered and annealed: castings oil tempered and annealed, and simply annealed.	Delivered.

Total approximate weight, 575 tons.
Aggregate for Army, furnished by Midvale Steel Company, 168 tons; by Cambria Iron Works, 17 tons; total 185 tons excluding 70 tons of miscellaneous pieces.
Aggregate for Navy, furnished by Midvale Steel Company, 320 tons.

APPENDIX B.

INITIAL TENSION IN GUN CONSTRUCTION.

[DISCUSSED WITH REFERENCE ESPECIALLY TO ITS APPLICATION IN STEEL-CAST GUNS.]

The object here will be to show what state of initial tension should be introduced in a hollow steel casting to put it in condition to resist the greatest interior pressure compatible with the dimensions of the cylinder and the quality of its metal. It is immaterial to this discussion whether the tension be introduced in cooling as with a hollow casting, or whether the casting be made solid, then bored and put in the proper state of tension by subsequent operations—provided only the metal is sound and good throughout.

To make the resistance to interior pressure a maximum, the state of initial tension should be such that when the pressure acts from within, the thickness of metal though the wall of the piece should be, as nearly as practicable, uniformly strained to the elastic limit of the metal.[a] The aggregate resistance of all the cylindrical laminæ would then evidently be a maximum, and it is this aggregate resistance which holds the interior pressure in equilibrium. In the initial state of a gun or cylinder constructed to fulfill this object, the interior portion of the wall rests in a state of tangential compression which is greatest at the surface of the bore, and the exterior portion in a state of tangential extension which is greatest at the outside surface. The strains of compression and extension are in equilibrium—the aggregates of the two being equal quantities. There will be a neutral lamina in the wall where the tangential strain is virtually zero, and from this locality the compressions should increase progressively toward the bore and the extensions, likewise, toward the outer surface. If the initial tension be properly regulated, the maximum place of strain will be at the surface of the bore, hence if the tangential compression there be limited to the elastic limit of the metal under compression the strain will nowhere exceed the elastic limit of the metal.

To illustrate the problem, take the case of a gun of 8 inches caliber, having a thickness of wall in front of the powder chamber equal to 1½ times the caliber of the gun.

Let—

P = Interior pressure per square inch.
ρ = Force corresponding to compression of metal.
θ = Force corresponding to extension of metal.
$\left.\begin{matrix} p \\ t \end{matrix}\right\}$ The radial pressure and tangential tension for the state of action, at any point at the circumference of a circle of radius r.
$\left.\begin{matrix} p' \\ t' \end{matrix}\right\}$ = Similar quantities for the state of rest.
R_0 = Radius of bore, and R_1 = exterior radius of cylinder.
E = Modulus of elasticity of metal.
ρ and θ may not exceed the limit of elasticity of the metal under free tests.

Considering the section in front of the powder chamber, we have $R_0=4$ and $R_1 = 16$ inches, and, as representing the forces which would cause the limit of elastic displacement of the metal to be reached under tests of free specimens, the following values are considered fair, viz:

$$\rho = 40{,}000,\ \theta = 35{,}000 \text{ pounds per square inch.}$$

The following equation gives the value of the interior pressure or the elastic resistance upon the supposition that the surface of the bore undergoes a range of

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[a] It will be shown hereafter that for a given quality of metal a condition of uniform strain throughout the wall *equal* to the elastic limit of the metal can be attained for a certain thickness of wall only, that is for a given value of the ratio $\frac{R_1}{R_0}$ in which R_1 represents the exterior and R_0 the interior radius of the piece.

dilatation, from the state of tangential compression represented by ρ to the state of tangential extension represented by θ, viz:

$$P = \frac{3\,(R_1^{\frac{2}{3}} - R_0^{\frac{2}{3}})}{4R_1^{\frac{2}{3}} + 2R_0^{\frac{2}{3}}}\,(\rho + \theta) \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)^a$$

The relation between P and θ, such that for a given value of P, θ or the tangential extension (otherwise expressed by $\frac{\Delta r}{r}E = \theta$) shall have a uniform value throughout the thickness of the wall, is expressed by the following equation, viz:

$$\theta = \tfrac{2}{3}\,\frac{P}{\left(\frac{R_1}{R_0}\right)^{\frac{2}{3}} - 1} = aP \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)^b$$

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[a] Derived from equation A, p. 27, Note 35, making $l = 0$. **Strictly speaking, the maximum resistance in any case should be limited to preserve the metal from excessive displacement, whether by tangential extension or radial compression (in state of action), but the *initial state* which would insure a maximum resistance is the same in either case, and for the present we will neglect the limit of radial compression which would give a less value for P and would be derived from equation B, p. 27, Note 35.**

[b] **Deduced by Lieut. William Crozier, Ordnance Department, U. S. Army, as follows:**

From the first of the expressions, p. 3, Note 35, with $q = o$, we have:

$$\frac{\Delta r}{r} = \frac{1}{E}\left(t + \frac{p}{3}\right) = \frac{\theta}{E}$$

whence

$$\theta = t + \frac{p}{3} \quad \ldots\ldots\ldots\ldots\ldots\ldots (a)$$

The interior pressure estimated for any radius r intermediate between R_0 and R_1 will be in equilibrium with the sum of all the tensions acting in the thickness $R_1 - r$, and we have:

$$p\,r = -\int_{R_1}^{r} t\,dr = -\int_{R_1}^{r}\left(\theta - \frac{p}{3}\right) dr$$

Differentiating and reducing,

$$pdr + rdp = -\left(\theta - \frac{p}{3}\right) dr,$$

$$rdp = \left(-\theta + \frac{p}{3} - p\right) dr = -\left(\theta + \tfrac{2}{3}p\right) dr$$

$$\frac{dp}{\theta + \frac{2}{3}p} = -\frac{dr}{r} \quad \ldots\ldots\ldots\ldots\ldots\ldots (b)$$

Intergrating between the limits r and R_1,

$$\tfrac{3}{2}\,l\left(\theta + \tfrac{2}{3}p\right) = -lr + lC$$

For $r = R_1$, $p = o$, then:

$$\tfrac{3}{2}\,l\left(\theta + \tfrac{2}{3}p\right) - \tfrac{3}{2}\,l\theta = lR_1 - lr$$

$$l\left[\frac{\left(\theta + \frac{2}{3}p\right)^{\frac{3}{2}}}{\theta^{\frac{3}{2}}}\right] = l\left(\frac{R_1}{r}\right)$$

$$\left(\theta + \tfrac{2}{3}p\right)^{\frac{3}{2}} = \frac{R_1}{r}\,\theta^{\frac{3}{2}}$$

$$p = \tfrac{3}{2}\,\theta\left[\left(\frac{R_1}{r}\right)^{\frac{2}{3}} - 1\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots (c)$$

Substituting the value of θ from (2) in (1), combining the two equations, we find:

$$P = \frac{3\,(R_1^2 - R_0^2)\,\rho}{(4\,R_1^2 + 2\,R_0^2) - 3\,(R_1^2 - R_0^2)\,a} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

It is evident from this equation that the greatest possible value for ρ will give a maximum value for P. Substituting known values ($\rho = 40{,}000$, etc.), we find:

$$P = 38{,}910 \text{ pounds per square inch,}$$

and this value in (2) gives: $\theta = 17{,}067$ pounds per square inch, from which $\frac{\Delta r}{r} = 0.00058852$ is the extension per linear inch, uniform through the thickness of the wall for $P = 38{,}910$. Since P is a maximum, this value of θ is also a maximum under the condition for both, that θ shall be uniform. This condition is introduced principally with reference to a discussion of the state of rest of the system, to give a datum line from which to lay off the ordinates of the curve of initial tension, as shown hereafter. The maximum value of P, if we admit the full limit of tangential extension, is, properly speaking, 51,150 pounds, which is the value corresponding to $\theta = 35{,}000$ pounds and is derived from equation (1). The particular state where θ is uniform and equal to 17,067 pounds and P is equal to 38,910 pounds marks an intermediate stage, which, however, is entirely compatible with the greatest value for P, viz, 51,150 pounds. We ought not, however, to consider this latter an entirely safe pressure for the gun, since, as might readily be shown, this pressure would cause the laminæ near the surface of the bore to be overcompressed in a *radial* direction. The limit of tangential compression of bore, system at rest, being represented, as before, by $\rho = 40{,}000$, the value of P which would cause the limit of radial compression to be reached in the state of action is given by the following:

$$P = \frac{2\,(R_1^2 - R_0^2)}{2\,R_1^2 - R_0^2}\,\rho = 38{,}710 \text{ pounds} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)^a$$

This is the safe theoretical value for the pressure to which the gun might be subjected; it corresponds nearly with the value (38,910) which we have found would produce the uniform extension, $\theta = 17{,}067$ pounds, throughout the wall, and it would therefore be a good value to adopt in practice. The thickness here used (1½ calibers) would probably be a good value to adopt for a steel-cast gun made with initial tension.

CURVE OF INITIAL TENSION.

We now pass to a consideration of the system at rest—that is, the state in which the interior pressure is supposed removed. The curve of initial tension which is shown in fig. 1 (Pl. IV) is laid off for values of ρ below the middle line and for values of θ above that line. These values are equivalent to $\frac{\Delta r}{r}E$ and if we divide through by E for the several points of the curve we would obtain values representing the displacements of the metal at such points, and the curve does, properly speaking, represent the displacements (corresponding to ρ or θ) caused by the joint action of the radial pressure (p') and tangential tension (t') acting at the circumference described by radius r.

[a] From equation B, p. 27, Note 35, making l=o.

Substituting R_0 for r, p becomes P, then

$$P=\tfrac{3}{2}\,\theta\left[\left(\frac{R_1}{R_0}\right)^{\frac{2}{3}}-1\right]\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(d)$$

whence

$$\theta=\tfrac{2}{3}\,\frac{P}{\left(\frac{R_1}{R_0}\right)^{\frac{2}{3}}-1}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

In any state which we may consider (within proper limits of elasticity) the force, θ at a radius r, which is created by the action of the interior pressure P, is expressed by the following: [a]

$$\theta=\left(\frac{2\,R_0^2}{3(R_1^2-R_0^2)}+\frac{4\,R_1^2\,R_0^2}{3(R_1^2-R_0^2)}\times\frac{1}{r^2}\right)P\ldots\ldots\ldots(5)$$

If we substitute —P for P, the resulting value of θ will give the *change* that occurs in θ for the given variation in the pressure. We take that particular state of the system in which θ=17,067 pounds is uniform throughout the wall and for which P=38,910. Then from the horizontal line which represented this value of θ in fig. 1 we may lay off the several values found for changes in θ corresponding to given values of r. To refer the points of the resulting curve to the zero line of the figure and substituting P=—P=—38,910, the above equation is written,

$$\theta\,(\rho)=-\left(\frac{2\,R_0^2}{3(R_1^2-R_0^2)}+\frac{4\,R_1^2\;R_0^2}{3(R_1^2-R_0^2)}\,\frac{1}{r^2}\right)38910+17067\ldots\ldots\ldots(6)$$

The values of θ for r=4″.0, 4″.75, 6″.0, 8″.0, 10″.0, 12″.0, 14″.0 and 16″.0 are laid off in the figure to locate the curve, and are given in Table A, which follows.

It will be observed that at the point where the curve crosses the middle line the displacement is zero. The particular value of r for this neutral point is expressed as follows: [b]

$$r^2=\frac{2\,R_1^2\,R_0^2\left[\left(\frac{R_1}{R_0}\right)^{\frac{2}{3}}-1\right]}{R_1^2-R_0^2\left(\frac{R_1}{R_0}\right)^{\frac{2}{3}}}\ldots\ldots\ldots(7)$$

This value depends only upon the fixed dimensions of the cylinder; it is independent of the magnitude of the initial tension, hence, for a cylinder of given dimensions, every curve of initial tension (within proper limits) which might occur should pass through the same point. If the neutral point were found much removed from the place indicated, it would afford evidence of fault and probably hurtful strains. At the same time, also, there might be dangerous local strains, counterbalancing in effect, even though the neutral point were found at its true position. A good idea of the adequacy of the initial tension would be had by observing the expansion of a thin iron ring of metal detached next the surface of the bore, but in order to make a proper examination an entire section of the casting should be divided into thin rings, as exemplified in

[a] From equation (6) p. 4, Note 35, making as should be in the case P′=0.

[b] For this point, θ has the value given by the equation (2) or

$$\theta=\tfrac{2}{3}\frac{P}{\left(\frac{R_1}{R_0}\right)^{\frac{2}{3}}-1}.$$

Substituting this value for θ in the first member of equation (5), dividing through by P and reducing, we obtain the equation.

Notes on the Construction of Ordnance, No. 38. It would, of course, be necessary to make this examination, at least in part, in order to locate the neutral point.

The remaining curves shown on figs. 1 and 2 are deduced as follows:

First, take the state of action corresponding to P=38,910 and θ=17,067 constant throughout the wall. The two forces whose combined action produces the curve of uniform extension ($\frac{\Delta r}{r} E=\theta$) corresponding to θ are the radial pressure and tangential tension p and t, and the equations of their curves are given by formulas (c) and (a), viz:

$$p={}^3/_2\,\theta\left[\left(\frac{R_1}{r}\right)^{\frac{2}{3}}-1\right]. \quad \text{........(c)}$$

$$t=\theta-\tfrac{1}{3}\,p \quad \text{.....................(a)}$$

or, by combining these, the value of t expressed directly in terms of θ and dimensions of the cylinder becomes:

$$t=\theta\left\{1-\tfrac{1}{2}\left[\left(\frac{R_1}{r}\right)^{\frac{2}{3}}-1\right]\right\} \quad \text{........(a)}$$

Again, considering this particular state of action, we may pass to the state of rest by assuming the interior pressure removed, which is indicated by making P=—P, as was done to determine the curve of initial tension. The variation in the pressure at any point for radius r, corresponding to a variation in P, is expressed by the formula: [a]

$$p_1=\frac{R_0^2(R_1^2-r_n^2)}{r_n^2(R_1^2-R_0^2)}p_0=-1\,P \quad \text{........(8)}$$

p_0 is placed equal to — P, and this value being assigned evidently indicates the removal of the interior pressure, hence p_1 gives the variation of pressure in passing from the state of action to the state of rest. The pressure existing in the state of rest is then the algebraic sum of the pressure previously existing for the radius r in the state of action and the variation of that pressure, hence:

$$p'=p+p_1 \quad \text{-------------------------(9)}$$

The values of p to be introduced here are to be found from equation (c). The deduced values of p' give the curve of pressure for the state of rest shown in Fig. 1.

For the curve of tension in that state we have, similar to (a)

$$t'=\theta\ (\rho)-\tfrac{1}{3}\,p' \quad \text{--------------------(10)}$$

in which the values of θ are to be found from equation (6).

As before remarked, the curve of initial tension represents a curve of displacements due to the aggregate effect of the forces p' and t'.

Returning to the state of action shown in Fig. 2 and considering the pressure P increased from 38,910 to 51,150 pounds, we have a positive variation of 51,150—38,910=12,240 pounds in the value of P. The variations in the value of θ corresponding to this variation will be laid off in a positive direction from the line of uniform extension θ=17,067, but in order to refer to the middle line

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[a] The simplest form of equation (33), p. 26, Note 35, when $E_0=E_1$ (2 cylinders).

of the figure as the datum line we use the form of equation (6). The curve of extensions for P=51,150 is then determined by

$$\theta=\left(\frac{2\,R_0}{3(R_1^2-R_0^2)}+\frac{4R_1^2\,R_0^2}{3(R_1^2-R_0^2)}\times\frac{1}{r_r}\right)P+17067\ldots\ldots.(11)$$

in which P is equal to 12,240 pounds.[a]

The ordinates for the several curves as determined by the equations given for progressive values of *r*, together with the displacement per linear inch corresponding to ρ and θ, are given in the following table. The modulus of elasticity E is assumed to be 29,000,000 pounds. (See Table A.)

The indicated strains (values of $\frac{\Delta r}{r}$) under "Initial tension curve" are expressed in terms of the displacements per linear inch; they are negative or compressions from the bore to the neutral point and positive or extensions thence to the exterior.

The section to be examined should be preferably first turned and bored to the dimensions of the finished piece and then cut into concentric rings, say 1 inch in thickness. Before cutting, a light circle should be scored on the middle of the face of each ring and several diameters carefully measured. These measurements repeated after the separation of the ring will give a measure of the force, whether positive or negative, by which the ring was held in restraint. The mean expansion or contraction divided by the diameter of the measured circle will give the value corresponding to $\frac{\Delta r}{r}$, and this quotient multiplied by the modulus of elasticity of the metal will give the value ρ or θ, corresponding respectively to the measured expansion or contraction. If the diameter be called D and the measured change of diameter d, the expansions are as follows:[b]

[a] The curve designated approximate pressure curve for P=51,150 is so far fixed only by the ordinates at the extremities. The interior one is given and the exterior pressure is only the atmospheric pressure which is counted nil. The form of (8) and (9) would be applied to determine intermediate points of the curve.

[b] The method of conducting this test is explained in Notes on the Construction of Ordnance, No. 38.

TABLE A.

Radius.	State of action.							State of rest.			
	Interior pressure, 38,910 pounds.				Interior pressure, 51,150 pounds.			Pressure.	Initial tension curve (compressions and extensions).		Tension.
	Pressure.	Extensions.		Tension.	Pressure.	Extensions.					
	P	θ	$\frac{\Delta r}{r}$	t	p	θ	$\frac{\Delta r}{r}$	p′	ρ & θ	$\frac{\Delta r}{r}$	t'
Inches.	*Pounds.*	*Pounds.*	*Thousandths.*	*Pounds.*	*Pounds.*	*Pounds.*	*Thousandths.*	*Pounds.*	*Pounds.*	*Thousandths.*	*Pounds.*
R_0–4.0	38,910	17,067	0.58852	4,150	51,150	35,000	1.207	0.	−40,000	−1.3793	−40,000
4.75	31,930	"	"	6,425	——	——	——	5,090	−23,905	−0.82431	−25,600
6.0	23,630	"	"	9,190	——	25,340	0.8738	7,780	− 9,260	−0.31931	−11,350
[a] 7.6	16,460	"	"	11,580	——	——	——	7,550	0.	0.00000	− 2,520
8.0	15,040	"	"	12,055	——	21,960	0.75725	7,255	+ 1,505	+0.0519	− 920
10.0	9,420	"	"	13,930	——	20,395	0.70327	5,375	+ 6,485	+0.22362	+ 4,695
12.0	5,410	"	"	15,265	——	19,545	0.67395	2,875	+ 9,190	+0.31690	+ 8,230
14.0	2,385	"	"	16,275	——	19,030	0.65621	1,590	+10,820	+0.37310	+10,290
R_1–16.0	0	"	"	17,067	0.	18,700	0.64483	0.	+11,880	+0.40965	+11,880

[a] Neutral point of initial tension curve.

$$\frac{D}{+d}E=\rho \text{ and } \frac{D}{-d}\varepsilon=\theta \ldots\ldots\ldots\ldots (11)a$$

The powder chamber would be made, we will say, with a diameter of 9.5 inches or $R_0=4.75$. In order to avoid the disturbance of the initial state which would result from enlarging to this size a bore made somewhat less than 8 inches in the rough, it would appear advisable to make the chamber nearly full size in the rough form before introducing the initial tension by either method that might be used. However this may be, the uncertainties of the manufacture are such that it is unimportant to consider here the disturbance which might arise in reaming out the chamber, and we will assume the interior surface there to be also compressed tangentially to the limit $\rho=40{,}000$.

Applying equation (1) we find, for the limit of tangential action (to compare with $P=51{,}150$ for the section in front of the chamber):

$P=49{,}130$ pounds per square inch.

The value which P would have when the extension θ became uniform throughout the wall is found from equation (3), viz, $P=40{,}320$, and the corresponding value of the uniform extension from equation (2) is $\theta=21{,}554$. Observe in this case that the values of P and θ for this particular state of action are both greater than for the corresponding state for the thicker section in front of the powder chamber where $P=38{,}910$ and $\theta=17{,}067$.

CHARACTERISTICS OF THE RESISTANCE OF CYLINDERS DEPENDING UPON RADIAL DIMENSIONS AND MODE OF CONSTRUCTION.

It will be seen that the values of P from equation (1) for the limit of tangential action decrease with the thickness of the wall, while those of P from equation (3) involving the uniformity of strain increase as the thickness decreases. This may be readily seen also from an inspection of the equations, and if we should plot the loci of the values of P, considering R_0 as a variable with successively increased values, from equations (1) and (3) the two lines would intersect within the limits of the wall. The value of the radius R_0 corresponding to this point of intersection where the two values of P are equal marks the interior radius of a cylinder (supposing R_1 to remain 16 inches and the constants θ and ρ as before) in which the extension is uniform and equal to the limit (θ) 35,000 when P has its maximum value for the limit of tangential action. In a cylinder with such interior radius the whole of the metal would be worked to its tengential limit and there would be a maximum utilization of the metal in the resistance offered to an interior pressure.

To make the case more general, let us find the value of the ratio $\frac{R_1}{R_0}=b$ such that θ shall be uniform throughout the wall and equal to its maximum value when P is a maximum for any cylinder.

The two equations of condition are (1) and (2); we must equate the value of P from these and find $\frac{R_1}{R_0}$. Placing the values of P from (1) and (2) equal, we have:

$$\tfrac{3}{2}\,\theta\left[\left(\frac{R_1}{R_0}\right)^{\frac{2}{3}}-1\right]=\frac{3(R_1^2-R_0^2)}{4R_1^2+2\,R_0^2}(\theta+\rho)$$

Substituting $b=\frac{R_1}{R_0}$ and reducing

$$\theta\, b^{\frac{2}{3}}-\theta=\frac{b^2-1}{2\,b^2+2}(\theta+\rho)$$

whence $$b^{\frac{8}{3}}-\frac{3\theta+\rho}{2\theta}b^2+0.5\,b^{\frac{2}{3}}+\frac{\rho}{2\theta}=0 \ldots\ldots\ldots\ldots (12)$$

From this equation, substituting $\rho = 40{,}000$, and $\theta = 35{,}000$, we find

$$b = 2.4722.$$

This value applies to the particular case in question where $\theta = 35{,}000$ and $\rho = 40{,}000$. If we retain $R_1 = 16$, we have $R_0 = \frac{R_1}{b} = 6.472$ inches or a bore of 12.94 inches, and a thickness of wall of 9.53 inches instead of 12 inches, as originally considered in the section in front of the chamber. With this new value of R_0 and given constants we find the value of P from either of equations (1), (2), or (3) to be 43,490 pounds. The maximum resistance is of course decreased (from 51,150 pounds) by this decrease of the thickness, but the given ratio determines the least weight of metal that will withstand an interior pressure of 43,490 pounds, and also indicates the most economical use of the metal considering the tangential limit of extension alone. If the interior radius be fixed, as, for instance, $R_0 = 4.75$ (chamber section) we find $R_1 = b \times 4.75 = 11.743$, or a cylinder with 9.5 interior and 23.49 exterior diameter should support this pressure of 43,490 pounds.

If $\theta = \rho$, equation (12) becomes:

$$b^{\frac{8}{3}} - 2b^2 + 0.5\ b^{\frac{2}{3}} + 0.\ 5 = 0 \ldots\ldots\ldots\ldots\ldots (13)$$

and from this we find,

$$b = 2.2946.$$

Then in any case, if $\theta = \rho$, the ratio $\frac{R_1}{R_0} = 2.3$ will, if R_0 or R_1 be assumed, fix the dimensions of a cylinder (made with full initial tension or assembled under such shrinkage that the compression of the bore shall equal ρ), which will give a maximum resistance to tangential extension for the least weight of metal.

From this value of b we find the thickness of the wall expressed in terms of the interior radius:

$$b = \frac{R_1}{R_0} = 2.2946$$

and

$$R_1 - R_0 = 1.2946\ R_0.$$

If the walls were thicker than 1.3 R_0, the condition of uniform extension expressed by equation (3) would be reached before the resistance of the gun was fully developed; if the wall were of less thickness than 1.3 R_0 the state of uniform extension could not be reached without the tangential extension exceeding the limit θ.

The values of P which we have just discussed would cause the radial compression at the surface of the bore to be exceeded in the state of action. Based on this limit the value of P for the chamber section, derived from equation (4) would be 38,156 pounds to compare with a similar value of 38,710 pounds for the section in front of the chamber. It will be generally considered safest and best not to subject a gun to pressures much exceeding the value of P here indicated.

If we equate the values of P from equations (1) and (4) we can determine a value for the ratio $\frac{R_1}{R_0}$ such that the limits of tangential extension and of radial

compression would be simultaneously reached in the state of action. We have, supposing $\rho = \theta$, from equations (1) and (4)

$$\frac{3(R_1^2 - R_0^2)}{4\ R_1^2 + 2R_0}(\rho + \theta) = \frac{2(R_1^2 - R_0^2)}{2\ R_1^2 - R_0}\rho$$

Making $\rho = \theta$, and reducing, also placing $\frac{R_1}{R_0} = C$;

$$\frac{3}{2\,C^2+1} = \frac{2}{2\,C^2-1}$$

whence $$C = \sqrt{\tfrac{5}{2}} = 1.581,$$

Or, in terms of the thickness and the interior radius,

$$R_1 - R_0 = 0.58\ R_0.$$

From this last it appears that if the thickness of wall exceeds 0.58 R_0, the cylinder will first fail, in action, from radial compression and the theoretically safe value of P would be derived from equation (4). If the thickness were less than 0.58 R_0 the cylinder would fail first from tangential extension, and equation 1 would be applied to find the value of P. These discussions will be understood to refer to a cylinder having full initial tension or more generally to a built-up gun in which the tube is compressed to the limit in the state of rest.

If we consider a simple cylinder without initial tension the limit of safety would always first be passed under tangential extension when subjected to an interior pressure only. The equations which give the pressure to be safely supported in this case are for tangential extension and radial compression, respectively. (See p. 6, Note 35) :

$$P(^1) = \frac{3(R_1^2 - R_0^2)}{4\,R_1^2 + 2\,R_0^2}\theta, \qquad P(^2) = \frac{3(R_1^2 - R_0^2)}{4\,R_1^2 - 2\,R_0^2}\rho$$

Since the denominator of the first exceeds that of the second in the sum of $4R_0^2$ and since θ is for the metals used in gun construction, either equal to or less than ρ, the safe, that is the least value of P, will be found from the first equation which corresponds to the limit of tangential resistance.

APPENDIX C.

ALLEGED FAILURES OF STEEL GUNS.

The following is in reply to the statements made in Appendix C of a report adopted by the Chamber of Commerce, New York City, February 3, 1887, in regard to "Failures of steel guns."

The statement published in the aforesaid report does not include a single authenticated case of disastrous failure of a gun representing the modern type of built-up steel guns such as are now being made in the United States. And a large majority of the cases cited refer to guns which were made largely of wrought iron. Herewith follows the fourteen (14) separate cases of alleged "failures of steel guns," contained in the report of the Chamber of Commerce together with a counter-statement of each case prepared from official or other authentic source of information. And it may be remarked that the source of information used in preparing the report of the Chamber of Commerce has been found to be frequently the first sensational accounts of the affairs published in newspapers, sometimes through the instrumentality of rival business firms.

(*1*) *The 6-inch gun aboard the Active.*

Six-inch steel gun; burst, using half a charge of powder; investigation by boards could not explain it. (H. M. S. *Active.*)

This was not a steel gun. It was an English construction, now abandoned, comprising a steel tube reinforced with a wrought iron coiled piece. The gun burst in the unhooped portion of the chase. It was a gun designed some five years since, and made too light in the chase. The cause of the failure has been sufficiently explained by the order since adopted, to place hoops upon the chase of all guns like it.

(*2*) *The gun aboard the Canada.*

Gun burst, killing one man and wounding four others. (H. M. S. *Canada.*)

The cause of this accident was a premature explosion of the charge, which occurred before the breechblock was properly closed.

It involved no fault of the material of the gun. The gun was not burst, only the charge was blown through the breech to the rear.

(*3*) *The 12-inch gun of the Collingwood.*

Twelve-inch steel rifle burst with 3-4 charge, 221 pounds of powder, 714-pound shot; tube burst 8 feet from muzzle and split the pocket. (H. M. S. *Collingwood.*)

The *Collingwood* guns were not steel guns. They were an English construction, now abandoned, consisting of a steel tube reinforced by several mild steel coils in front of the trunnions and by a coiled wrought-iron jacket and breech piece. A considerable portion of the muzzle end of the tube was not hooped, and was, moreover, but 2½ inches in thickness at the neck of the chase. The tube broke in front of the hooping, but it has since been demonstrated that the

steel (of old manufacture) was inferior in quality, and that the tube forging had not been annealed after oil tempering. These guns failed primarily because of bad methods of treating the steel, and again because they were of weak construction generally.

(4) *The 100-ton Armstrong gun.*

One hundred-ton Armstrong gun burst on the Italian ironclad after a very few rounds. (*Duillo.*)

The 100-ton Armstrong gun which failed aboard the *Duillo* consisted of a thin steel tube reinforced by wrought-iron coils. In firing the gun the coils parted at the joints, and the steel tube being left unsupported broke away with them.

(5) *The 7-inch Armstrong gun.*

Seven-inch Armstrong gun burst on Argentine vessel (*Pavonia*).

This is undoubtedly a mistake. The accident noted perhaps refers to a gun built of wrought iron and steel. Reports state that a 6-inch Armstrong gun of this character aboard the Argentine vessel *Parana* was found to be cracked in the tube. There was no bursting. The gun was replaced by the maker.

(6) *Bombardment of Alexandria.*

Some of the guns failed at the bombardment of Alexandria. (Alexandria.)

There were no modern steel guns of large caliber aboard the ships at Alexandria. All were muzzle loaders, of Frazier system of construction. A 40-pounder Armstrong was the heaviest steel gun aboard the fleet. The sum of the failures amounted to a cracking of the tube in one or more of the large muzzle loaders (old style).

(7) *One hundred-ton Armstrong guns.*

All the 100-ton guns furnished the Italian Government by Armstrong & Co. have been condemned, although none of them have been fired 50 rounds. (*Duillo, Dandolo, Lepanto.*)

These 100-ton Armstrong guns are made of wrought iron and steel. We do not know how many of these failed, but the sole cause of failure arose from defective jointing in the bore of the two parts which compose the tubes of these guns. Nothing in the failures tells against steel. Moreover, it is believed that the guns are still in service.

(8) *Fourteen-inch rifle.*

Four 14-inch rifles of latest design in English service failed in July last. (*Ajax.*)

The so-called failure of the guns on the *Ajax* consisted simply in a damaged vent. This was repaired, and the guns continued in service. Moreover, it was an old construction, and not the latest design at all. Again, the heaviest gun aboard the vessel was 12-inch, designed in 1871.

(9) *The 100-ton steel gun.*

One hundred ton steel gun blew off its muzzle at the proving ground at St. Chamond, Venice.

This probably refers to a 75-ton French gun, in which a short piece of the unhooped portion of the muzzle is said to have been broken off in firing at

Ruelle, France, but the gun was not thereby rendered unserviceable. Certainly at the time of this accident there had been no 100-ton French steel guns made. Nor was the gun that failed hooped to the muzzle, as is now practiced.

(*10*) *Two 120-ton steel Krupp guns.*

Two 120-ton steel Krupp guns, made for the Italian Government for coast defense, failed in proof and were not accepted. (Spezzia.)

This statement is directly contradicted in a letter written by Mr. Krupp, dated November 5, 1886, to United States Consul Potter, of which the following is an extract: "*In none* of these four guns (referring to the whole lot ordered by Italy) has the slightest defect been traced; on the contrary, even No. 19464 of these guns, which had fired 82 rounds, partly with considerably heightened charges, is in *completely fit state for any service.*"

The report of the failure of these guns was propagated by a rival firm.

It is known that three of the four guns have been accepted by the Italian Government, and are now at Spezzia, Italy, awaiting emplacement in the fortifications. These guns were shipped by Krupp in September, 1886, and before being shipped were subjected, respectively, to 9, 11, and 12 proof rounds each at Krupp's works. The fourth gun was not taken by Italy and Krupp has a fifth gun in course of completion to fill the original order. This fourth gun has been retained by Krupp, and used by experimental firings to test powders—the proof having been continued as stated above to the number of 82 rounds, the gun still remaining in serviceable condition. The eightieth round was fired with a charge of 847 pounds of powder and a projectile weighing 2,315 pounds, giving the measured pressure of 19.5 tons per square inch with the Rodman gauge, and 18.765 tons with the crusher gauge, an initial velocity of 1,900 feet per second, corresponding to 57,933 foot-tons of muzzle energy, and a penetration of 41 inches of iron at the muzzle, or 39.4 inches at 1,094 yards. In regard to the condition of this gun after the eighty-second round, Krupp's firing record states that there is no enlargement of the bore, and that in the powder chamber, originally 93.03 inches in length, a maximum elongation of 1 mm., or 0.04 of an inch, nearly, has been observed.

(*11*) *The 6-inch Navy gun.*

One 6-inch steel rifle at the Washington Navy-Yard, for the new cruiser, condemned for defects found in the bore upon final inspection, and two out of five guns of same class, show similar defects in the bores. (*U. S. Navy.*)

There was but one gun condemned for this cause, and that gun was taken apart in order to use the sound pieces in the construction of a new gun.

(*12*) *The 8-inch Army gun.*

The new 8-inch steel rifle made for United States Ordnance Department, of Whitworth steel, showed enlargement of the tube after twenty-four rounds, so that firing was suspended and the gun taken to the machine shop to be reenforced by additional hoops. (*U. S. Army.*)

This 8-inch United States Army gun is an experimental gun. The necessity for chase hooping was anticipated before any firing was done. The enlargement of the bore did not injure the gun for any future service, and has been corrected by hooping the chase. Seventy-seven rounds have been fired from the gun since the chase hooping, and there is no sign of any weakness or defect. The tube used in this gun, which was the only part of the metal that indicated weakness

in the first state of the gun, was procured from abroad, and its manufacture was not supervised by the Department.

(13) Krupp guns at the siege of Paris.

At the siege of Paris more than half of the heavy Krupp guns failed during the first fortnight of the bombardment, and during the Franco-Prussian war more than 200 Krupp guns burst. (Major Haig, in a report read before the Royal Artillery Institution.)

We will note, in the first place, that no heavy guns—that is, seacoast guns—can be included in this statement; and for the rest, it is wholly denied by a letter written by Mr. Krupp in 1878. His letter stated that of the 17,000 of his guns made between the years 1847 and 1878 only 18 had failed (about 1 per 1,000), and those failures had been mainly in experimental firings to extremity, or on account of the square angles in the slot made for the breech-block, which defect he had remedied in his later guns. Finally, the report refers to steel guns made more than sixteen years since.

To this it may be added that a carefully prepared table, made up in Italy, records the failure of but 11 Krupp guns between 1864 and 1882.

(14) Gun in after-barbette of Collingwood.

The Admiralty Gazette says: "The bursting of the 43-ton gun on board the Collingwood startled the country. But the Naval Annual, recently issued by Lord Brassey, discloses the astounding fact that 'similar guns in the after-barbette of the Collingwood have been since tested, and one of them burst when fired with a charge of powder of about two-thirds the weight of that used in the trials of the guns in the fore-barbette.' This has been carefully kept quiet hitherto, and should, unquestionably, be investigated by the ordnance inquiry commission." (Army and Navy Journal.)

In the Naval Annual, page 175, there is simply a note stating the well-known failure of the single *Collingwood* gun, namely, that in the after-barbette. This case is the same as that referred to in reply (3). There was only one gun burst, and that instance was published everywhere.

In preparing the foregoing replies every endeavor has been used to reach a fair statement of the facts, by a reference to the files of the Office of Naval Intelligence in cases wherever necessary. In summarizing the whole number of cases it is seen that no instance is cited where a modern steel gun has failed to such an extent as to render it unfit for service. The French gun in which the muzzle was blown off was an all-steel gun, but was not hooped to the muzzle, and the gun was continued in use by facing up the muzzle end of the tube. Moreover, the companion guns of this model were shortened for service to the length of the one with which the accident occurred; this was adopted as an alternative to muzzle hooping. Except this case there are but three others in the list, viz: The 116-ton Krupp, the 6-inch navy, and the 8-inch army guns, q. v., which refer to modern steel guns; that is, four cases out of the fourteen. The case of the Krupp guns at the siege of Paris, q. v., whatever of truth there may be in the flatly contradictory statements made on either side is not one with which we are now concerned. The case of the second *Collingwood* gun (14) is an undoubted canard. There remain eight more, all of which refer to combined wrought-iron and steel guns, both breech and muzzle loading, and out of these we can find only three cases in which the guns were burst, viz: The 6-inch on the *Active*, one 12-inch on the *Collingwood*, and 100-ton Armstrong on the *Duilio*.

This conclusion receives confirmation from an official return submitted to the Parliament of Great Britain, dated January 29, 1887: "Showing the number, description, name of designer, place of manufacture, and position at the time, of the rifled iron and steel guns that have burst or been temporarily disabled through defective construction or from other causes in the land and naval services from 1875–76 to 1885–86." This list contains a total of 12 breech-loaders and 19 muzzle-loaders of all calibers. It includes but three breech-loading guns of 6-inch caliber or above, viz, the *Active* and *Collingwood* guns and one 7-inch Armstrong gun burst at Sandown Fort, October 14, 1882. These guns were all admittedly of a weak construction now entirely abandoned in England, and their failure has no bearing whatever upon the question of the endurance of modern steel guns.

N. B.—The very erroneous impressions conveyed in the report of the chamber of commerce as to the endurance of cast-iron rifles pure and simple, and their mistake in confounding the tubed guns with simple cast-iron guns (see their Appendix D) have been shown elsewhere in this paper.

A Discussion on Gun Making in the United States

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A DISCUSSION OF CAPT. ROGERS BIRNIE'S PAPER ON "GUN MAKING IN THE UNITED STATES."[a]

Lieut. Commander F. M. Barber, *U. S. Navy.*

Gentlemen: Captain Birnie's very exhaustive and correct treatment of the subject leaves nothing to be said except in the way of praise. The year 1887 will be memorable in the history of gun making in the United States from the fact that never before have the advocates of the different material for and methods of gun manufacture appeared before the various professional societies of the country and laid before these judges the variety of information, theory, and fact in possession of each for comparison.

Commencing with the Dorsey paper before the Naval Institute in January, we have had that of Mr. Metcalf before the Society of Civil Engineers, that of Mr. Morgan before the Society of Mechanical Engineers, renewed discussion of Mr. Metcalf's paper in the Society of Civil Engineers, the paper of Mr. Cowles before the Naval Institute, and, finally, that of Captain Birnie before the Military Service Institution.

At the close of the discussion before the Society of Civil Engineers Mr. Metcalf (who is an ardent and able advocate of steel-cast guns) paid a high tribute to the ability and knowledge displayed by our ordnance officers of the Army and Navy and congratulated the community on the fact that officers had at last been drawn out of their shells and had given the public the benefit of their information. I think that in coming out of his *shell* Captain Birnie has shown himself in this paper to be the largest sized Government mollusk that has yet appeared in print. His assertions are supported by official records, his theories are sound and are demonstrated by mathematical calculations that are irrefutable, and they are proved by experimental observation of the most elaborate character. The conclusion which he draws that the built-up forged steel gun, which has been adopted by both Army and Navy, is at the present day the best gun both from the manufacturer's and an artillerist's point of view, seems to be perfectly sound and inevitably deducible from the facts in the case.

His mathematical discussion of the steel-cast gun and the line of practical investigation which should be followed in order to develop its greatest possibilities is new and particularly interesting, in view of the fact that there are still many people in the United States who believe that the true solution of the great gun problem is to be found in making it of one piece of unforged cast steel. In connection with this matter it is to be noted that within the week the newspapers have reported the bankruptcy of the "Compagnie des Fonderies et Forges de Terre Noire," in France, a wealthy company that a few years ago employed more men than any other in the world, Krupp's not excepted. This firm made a specialty of unforged cast steel, but were never able to get beyond hoops in even small-sized guns. They were the most famous firm in the world for this kind of work and their process has been adopted with success by the

[a] Read before the Military Service Institution at Governors Island, New York Harbor, November 26, 1887, and printed in Monograph VIII.

Swedish Government at Bofors for making solid steel guns up to 4 inches in diameter. Above that, however, to 6 inches the guns are hooped; beyond that they do not go at all.

The present published condition of the 6-inch steel-cast guns of the United States, referred to by Captain Birnie on page 65, is as follows: "The Bessemer gun has been successfully cast; it is solid, and is now being rough bored. The open-hearth gun is to be cast hollow on the Rodman principle, but the attempt has not yet been made. It may be interesting to tabulate the physical characteristics thus far published regarding the metal of the Bessemer gun and those required and obtained by the Naval Bureau of Ordnance in the tubes and hoops of the 6-inch forged-steel guns made at Midvale."

Specifications as bid for Bessemer gun: Tensile strength, 80,000; elastic limit, 40,000; elongation, 7 per cent.

Published as obtained after casting (unofficial): Tensile strength, 95,000; elastic limit, 50,000; elongation, 12 per cent.

Midvale tube, after treatment (official): Tensile strength, 80,000; elastic limit, 35,000; elongation, 22 per cent.

Midvale hoops, after treatment (official): Tensile strength, 96,000; elastic limit, 47,000; elongation, 15 per cent.

The effect of treatment is to increase the tensile strength and elastic limit and to diminish the elongation, the latter by about one-third or one-fourth, and the Bessemer gun would not appear to have elongation enough even before treatment. It is to be hoped that the Military Institute will be able to obtain and publish with this discussion the results of the official tests soon to be made of the specimens taken from different parts of the Bessemer gun.

Captain Birnie's paper forms a fitting closing to the copious discussions of the year and will furnish a final and convincing proof to the manufacturing community that the constituted authorities of the Army and Navy know what they want in gun metal and how to use it after they obtain it.

Brevet Brig. Gen. H. L. Abbot, *Colonel, Corps of Engineers.*

Captain Birnie has compressed into small space a very instructive statement of the results of a series of experiments scattered through a term of years and not heretofore easy of access. It is no small service to bring into one picture the tombstones of past failures and to group them in a manner to indicate where the path of safety for the future is to be found. This he has done, and, I trust, in a way to carry conviction to disinterested minds. It is time to recognize that there is such a thing as a science of gun making and that certain theories which a quarter of a century ago were worthy of experimental investigation are no longer so to-day.

As an engineer, I am specially interested in the experiments with mortars in progress at Sandy Hook: There can be no doubt that this weapon is destined to play a more important part in the defense of our coasts than heretofore. It has been developed abroad under the name of Howitzer until a gain of fully 200 per cent in effective force of impact and a gain of upward of 300 per cent in length of effective range have been secured. The cost of manufacture, and especially of emplacement, is small as compared with that of guns. The Fortification Board, of which Secretary Endicott was president in 1886, recommended 724 heavy mortars and 581 high-power guns of all calibers for the defense of our entire seacoast. Evidently the development of the best pattern and mode of construction is a matter of the highest importance; and it is earnestly to be hoped that the Ordnance Department is not to be hampered, as heretofore, in other directions, by the pressure of interested parties urging their own wares upon the attention of Congress.

While heartily concurring in most of the views expressed by Captain Birnie in this interesting paper, I am constrained to dissent from his estimate of the practical value of the pneumatic gun in coast defense. Its short range restricts its fire to the area obstructed by submarine mines, and we can not afford to make every shot which misses the enemy a countermine to destroy them, and thus open a route for his passage. The mines are indispensable, because steam vessels can force their way through any unobstructed channel under cover of darkness, whether the projectiles thrown at them contain gunpowder or dynamite; and we can not introduce a new weapon that directly antagonizes another of prime importance which it can not replace.

If it be suggested that the use of the "aerial torpedo" may be restricted to the period of the siege when the submarine mines having been destroyed by the enemy, he is ready to attempt to pass the forts, we must call to mind that this invention is more nearly allied to a mortar than to a gun in the character of its trajectory. Although an advocate of the use of vertical fire, where properly applicable, I draw the line where the target is in rapid motion. When the channel is once opened the ships will pass at full speed, and it will be of little use then to assail them with any kind of mortar projectile. Outlay invested in these pneumatic guns could, in my judgment, be better spent for other means of defense.

The weapon rests its claim for introduction into service upon its exclusive ability to throw high explosives with safety; but it is stated on good authority that mortar shells charged with 110 pounds of wet gun cotton are even now fired successfully in Germany, and improvements in the compositions of high explosives is making so rapid progress that there is reason to expect an early use for them even in guns. Under these circumstances I think the company has done wisely in preferring to bring their invention to the attention of the Navy rather than to that of the Army. As a counterminer to destroy submarine mines it may have value, although without actual proof I should be loth to assume that it could do more than moderately assist in the opening of that *known and well-defined channel from 4 to 6 miles long*, without which no armored ship will safely pass our forts. The gallantry of our enemies is assumed, but there will be conspicuous need for it in maneuvering an unarmed floating magazine, containing many tons of dynamite under the fire of modern high-power guns mounted on land at a range of 1 or 2 miles.

Brevet Maj. J. B. CAMPBELL, *Captain Fourth Artillery.*

Captain Birnie's paper begins by mentioning the period of brief superiority in ordnance that the genius and industry of Rodman and Dahlgren vouchsafed the United States, and laments the decline in the art of gun making in our country, except in the direction of small arms and machine guns.

He pointedly remarks that for the inception and proof of the principles and practice of gun construction now acknowledged to be fundamentally correct, the world is indebted to citizens of the United States, and leaves it to be inferred that the want of support and development of these practices in our country is due to want of appropriations by Congress.

He doubts the advisability of changing the direction or control of armament construction from that of personal responsibility, assisted by a body of life-long officers, trained for their business at Government expense, to any other plan, and hopes that, in any event, the decision of the question *what guns the Army shall use* will be intrusted to military men. If by military men he means those who are to use the guns in repelling danger, he will have a large following. It will be otherwise if the term is construed to mean the noncombatant corps of designers, constructors, and inspectors that has heretofore controlled this

question. Looking beyond the United States, it will be observed that almost all of the really great progress in gun making has taken place in countries that have no national foundries and gun shops, and no exclusive corps of ordnance designers and manufacturers. In fact, the nations who were not encumbered with the latter were the first to derive benefit in their armament from the ingenuity and skill of private inventors and manufacturers. Whitworth and the Elswick works in England occupy the attention of the world rather than the national establishment at Woolwich, and the latter has been successively driven from almost every one of its assumed positions by the superior practice and productions of the finest establishments.

Krupp and Grusen are the dependence upon which the Government of their country, as well as several foreign ones, rely. France, accepting through defeat and humiliation the lesson taught her by the national patrons of private enterprise, realized that the official exclusiveness and perfunctory ruts of the national shops and foundries of Gavre, Bourges, Ruelle, and Nevers were a poor reliance in the supreme moment, and called to her aid in the necessity for reorganization and rearmament the science, skill, emulation, and progress of St. Etienne, Le Creusot, and St. Chamond.

Austria, with her Vienna establishment, her Von Lenk and Von Uchatius, and their years of official failures, wholly or in part, has followed the example of her more youthful and progressive neighbor, Italy, and now gets her armament where it can be best, most successfully, and cheaply made.

In Russia only do government establishments appear to prosper and produce acceptable material. It is a question whether this is not to be attributed to the purely despotic and personal government, where the sovereign's will, unimpeded by turbulent scheming and pipe-laying legislatures says *what* shall be done, *how* it shall be done, and *who* shall do it. It is for the Czar's interest and safety to get the best attainable to serve him in all capacities, and he does it. Even in Russia, following the general rule, government works are mere imitators. Rarely if ever are original conceptions produced by public functionaries.

A small gun shop for experiment and investigation would probably be a desirable plant for the United States to possess, but the Government, whose chief and only mission should be to make and administer the laws and protect the country from exterior and interior harm, should never be a manufacturer or enter into any other kind of business, for the simple reason that in competition with private enterprise it falls behind and becomes extravagant; this will ever be the case as long as a hired agent is inferior to a principal. The vitality and progress inspired by successful competition and supported by the acumen necessary to avoid the expense of failure, can not be expected of those whose existence is equally comfortable in failure or success. Let the Government officers select the gun best suited for the purposes desired—or invent it, if they can—inspect the material of which it will be made, superintend if you will the work of construction (although I believe neither of these are done in Europe), and test it when completed; but let the American manufacturer make it.

The running history of guns, both conceived of and made, is very interesting and instructive, accurate, and as full as could be made in the narrow limit of an evening lecture.

The explanation of the principles of construction of built-up steel guns is clearly and concisely put, and should go far to convince all of the fact that such guns, when they are properly designed, and when the mechanical construction accurately and faithfully follows the design, are within reach, powerful, reliable, and safe, no matter what may be said of other guns. The worst that can be said against them is the great difficulty in accomplishing the minute mechanical accuracy of design that is indispensable to the safety and perfection of the

system in such large masses of metal; and of securing within them the desirable uniformity of required or assigned physical properties. The liability of latent interior defects in the masses has practically disappeared with the introduction of improved metallurgic methods, and in the latest, or De Bange development of the system, wherein by decreasing the dimensions and proportionally multiplying the number of the masses, their homogeneity is rendered more certain, the strength of the gun is increased, and the cost of the plant necessary to manufacture them is decreased. Captain Birnie has been a faithful student of, and an untiring investigator in, the interesting problem of the development of the built-up steel gun, and his modesty has concealed the fact that both the science and art of building steel guns on the principle of initial tension owe not a little to his industry and ability.

The steel wire-wrapped guns of Longridge, Woodbridge, Schultz, and Armstrong may really be considered as the ultimate development of the hooped or built-up gun. The perfect interior state of the walls of a gun, as far as initial strain is concerned, can be made to more nearly and surely approach theoretical requirement by wire winding them than by any other way. This construction is receiving attention in all countries interested in gun problems, and it is hoped experiments with it will not cease in the United States. While it is not condemned by Captain Birnie, he says little to encourage what he admits to be a promising problem.

Captain Birnie, strong in his faith and admiration of wrought-steel tubes, jackets, and frets, courageously attacks the rationality of attempting cast or homogeneous steel gun constructions. In these days of rapid development of the possibilities of metallurgy it is dangerous to predict what can not be done. But a few years ago it would have been thought madness to undertake to make a steel casting approximating in size to a 5-inch gun. To-day such a casting is an accomplished fact, and the faith of its artisans in its inherent goodness of quality and strength is almost as great as is that of Captain Birnie in his forgings. France and Italy have extensive and powerful armaments consisting of cast-iron guns tubed and fretted with wrought steel. It is within possibility that a vastly better gun could be made by substituting cast steel for cast iron in such a combination, and it does not require a superabundance of credulity to expect to see initial strain as surely and accurately engendered within a homogeneous steel gun as in a built-up one. Such an achievement would not be nearly as great an advance as has been made in the science of gun construction within the last fifteen years. Official conservatism must be kept out of danger of getting into a traveled rut. The trials and triumphs of Sir Henry Bessemer should ever be a warning restraint against unconsidered disapproval of the ideas of intelligent specialists and investigators. It is useless to say that the steel built-up gun marks the limit to improvement in ordnance with steel as the material to be used, and equally unwise to believe or assert that another metal or metallic alloy may not be found that, under proper treatment, will relegate steel, with all its noble and surprising properties, as far to the rear in the gun-making world as its intimate neighbors, cast and wrought iron, have been.

JOSEPH MORGAN, Jr., Esq.

So much has been written upon the subject of our proposed new ordnance, and the very complete and able résumé of Captain Birnie covers the ground so thoroughly, there is nothing more to say. The work in direction of new steel guns has been so well done by our ordnance officers that I hope they may be allowed appropriations to continue it. My own views on this subject are

well known. Whether our guns cost 10 cents or $1 per pound is not material, provided they are the most powerful tools of the kind to be had.

I believe forged and tempered steel of high elastic limit, properly assembled by shrinkage, gives the best guns known.

If material with an elongation of 7 to 10 per cent and reduction of area 5 to 7 per cent, with an elastic limit of 40,000 and ultimate of 80,000 is accepted, as in naval cast guns now under contract, why not use forged steel of 80,000 elastic limit, 135,000 ultimate, which has equal ductility, and raise the powder pressure. getting greater range and penetration?

THEODORE COOPER, Esq.

In Appendix B the author in his investigation makes an assumption which is a very common one, but which is an erroneous one, viz, that a metal having an elastic limit of 40,000 pounds per square inch, as determined by the usual method of applying one kind of strain (tension or compression) from the zero point of strain, can be subjected to alternating strains of +40,000 pounds to —40,000; or, in other words, that the compressive force ρ and the tensile force θ can each be worked to or near the above ordinary elastic limit.

Such a belief has been long prevalent and is still persistent. Many of the mysterious failures of our machines and structures are due to this false doctrine.

In 1867 Herr Wohler made a very valuable series of experiments upon iron and steel subjected to continued changes of strain of various kinds. These experiments were first published in English in Engineering, 1871, March to June.

From the results of these tests he concludes "that variations of strain may, with equal security, take place within the following limits, it being of course assumed that in all cases the maximum strain is less than that required to produce fracture under a stated load:"

1. Bars subjected to tension and compression:

Iron	+17, 120 pounds	to	—17, 120 pounds.
	+35, 310 pounds	to	0 pounds.
	+47, 080 pounds	to	+25, 680 pounds.
Cast steel for axles	+29, 960 pounds	to	—29, 960 pounds.
	+51, 360 pounds	to	0 pounds.
	+85, 600 pounds	to	+37, 450 pounds.
Untempered cast steel for springs	+53, 500 pounds	to	0 pounds.
	+74, 900 pounds	to	+26, 750 pounds.
	+85, 600 pounds	to	+42, 800 pounds.
	+96, 300 pounds	to	—64, 200 pounds.

2. Bars subjected to shearing strains:

Cast steel for axles	+23, 540 pounds	to	—23, 540 pounds.
	+40, 660 pounds	to	0 pounds.

Although these experiments extended over years and some of the test pieces were subjected to as high a number of tests as 132,000,000, it must not be assumed that the above limits are exactly determined even yet. They do, however, show that the capacity of a piece of metal to resist different kinds of strains is variable.

The explanation usually adopted is covered by the term "fatigue of metals," to my mind a very unscientific and absurd expression.

Upon reading the report of these tests when first published it seemed to me that a much more probable explanation was that the position of the elastic limit moved and should be measured from the initial strain; that the term "range of elasticity" would be more applicable. For example, in the case of his iron,

the elastic range, until we approach the breaking limit, would be about 35,000 pounds, whether measured from —17,000 or from 0.

To assume that a material having an elastic limit of 35,000 pounds would ultimately break down under strains not exceeding one-half of this amount on the fatigue theory would violate all conception of a perfect elasticity.

Whereas to accept the idea that our material did have an *elastic range* equal to 35,000 pounds, which must be measured between the extreme limits of our strains, is perfectly in harmony with a perfect elasticity.

In a recent number of Engineering, November 25, 1887, I find that Professor Bauschinger has made a series of experiments on the alteration of the elastic limit of iron and steel, extending over several years.

He concludes upon the point under discussion that "the elastic limit in tension is, in general, very different from that of the material when subjected to compression and artificially raising the elastic limit in tension, causes the limit in compression to be decreased, and this may even pass through the point of zero stress. In other words, a bar of steel or iron has two elastic limits, and whatever position these occupy on the scale of loads, the range between them is nearly a constant quantity. By alternately stretching a bar in tension and compression just beyond the elastic limits, these, after a certain number of repetitions, occupied positions equally distant from the point of zero load, and the limits thus obtained are called by Bauschinger the natural elastic limits of the bar. It was then noted that the stress corresponding to these limits sensibly coincided with that found by Wohler as the limiting stress to which a bar could be subjected to alternate tension and compression. It would thus appear that a bar will bear an indefinite number of repetitions of stress, provided the range of stress does not exceed the elastic range mentioned above."

This is a perfect confirmation of the views I have held for years, and is a satisfactory explanation of what is usually called the fatigue of metals.

Holding this belief, I do not think the compression at the bore plus the expected tension should exceed the elastic range of the material if the strains as determined by the ordinary formulæ are correct.

This would lead, I suppose, to a less initial compression at the bore and also a less tension at the exterior.

And if the strains from temperature are considered, a still further reduction would be needed. For a lineal dilatation of 0.0012 for 180° F., and a modulus of elasticity of 30,000,000, each 10 degrees of difference of temperature between the surface of the bore and the exterior, would cause a new strain of 2,000 pounds per square inch additional difference of strain between the interior and exterior.

How much such difference of temperature would amount to I leave to those better able to judge, though I would expect it to be considerable in rapid firing of heavy guns.

I leave to those who are better posted in the application of the theoretical formulæ to determine in what manner these views may affect the design and construction of guns.

It is very doubtful to my mind whether the theoretical strains due to the hoop-tension theory will obtain in practice. I should expect somewhat the same failure of correspondence between the theory and practice, as we find in the fiber stress of solid metal beams under the analogous theory of elastic-beam flexure.

J. R. HASKELL, Esq.

Captain Birnie, in his criticism on the multicharge gun, says: "Of the various experiments made, we have accounts of the performance of three guns only, viz, a 2½-inch gun tested at the Washington Navy-Yard, a 6-inch gun tested at

Reading, Pa., in 1870, and the 6-inch gun which was tested at Sandy Hook." Captain Birnie knows nothing about the many other experiments made with multicharge guns.

I commenced making and experimenting with these guns in connection with Mr. A. S. Lyman in 1855, and we worked in concert until 1863, since which time he has not been connected with it. He is now dead. These experiments have cost over $300,000 of private capital, and have consumed years of time. I never asked a dollar of Government aid until I had demonstrated the success of the multicharge principle.

In 1857, through the friendship of Gen. Winfield Scott and at his request, I obtained permission to test a 2½-inch accelerating or multicharge gun (which I had constructed) at the Water Battery at West Point. In 1857 and 1858 I made many experiments there. I had previously experimented with guns of different calibers, and made on different plans, but all embracing the accelerating principle.

The first official test was made at Fortress Monroe, Va., in 1858, before a board of artillery officers, of which Col. H. Brown was president. I conducted all these experiments in person.

It was after this that the 2½-inch bore gun was made, which was tested at the navy-yard, Washington, in 1863. Captain Birnie says this gun "penetrated a target of wrought-iron plates 5 inches thick, backed by 18 inches of solid oak timber. This gave a penetration of 'more than 2 calibers.' The firing was done at 200 yards, with a total charge of 6¾ pounds of powder and a steel projectile weighing 19¾ pounds."

Captain Birnie does not state the whole case. This target had been fired at three times before by a 5-inch Whitworth gun, which was unable to penetrate entirely through the 5-inch iron plate, and the gun was cracked at the third discharge. The 2½-inch multicharge gun was then put at the same place. The first shot fired did not strike true, but "wabbled," the shot breaking and sticking in the iron plate. The second shot struck fair, penetrated entirely through the target and backing, making a hole of about its own diameter, and struck the water some distance in the rear.

Subsequently the same gun was tried against a target representing a section of the original monitor turret, made of the same kind of iron, and formed in the same machine as the original turret. The target was improperly supported so that it fell when struck by the shot, which "wabbled" some and did not strike fair. The shot was broken in the target, but "penetrated 7½ inches, cutting a hole 3 inches by 3¼ inches." The officer in charge admitted that if the shot had struck fair, and the target had been properly secured, the shot would have penetrated entirely through the target—10 inches. He, however, refused to allow another shot to be fired at it.

At that time no gun in the world could penetrate more than 1 caliber, and few could do that. Here was a gun which actually penetrated 3 calibers, and which it was admitted could penetrate 4 calibers. What encouragement did it receive? Why, the officer in charge (who was subsequently Chief of Ordnance of the Navy) reported the above facts, and then remarked "that he regarded the gun as more curious than useful, and recommended that no further experiments be made with it."

The 6-inch multicharge gun tested before the Ordnance Board at Sandy Hook was made of very poor metal, the cast iron as well as the steel. The board reports, "It is admitted that the 6-inch gun is made of inferior metal." The endurance of this gun would therefore be no criterion by which to judge the system. Besides, the gun was rifled on a very defective system, the same as that now used in the new steel guns of the Army and Navy. This system

requires the use of either expanding or "slugging" projectiles, i. e., where the grooves and lands of the rifling are imprinted on soft metal bands at the instant of discharge. This kind of projectile creates unnecessary friction in the gun, helps to destroy it, and at the same time robs the shot of a great portion of its force.

I was forced to adopt this system, because I could not have the gun rifled as I desired by contract, and the treasurer of the company would not consent that any work should be done by the day. Had the gun been properly rifled it would have had much greater endurance in spite of the defective metal.

Captain Birnie states that after the tube was cracked "bands were shrunk on the chase of the gun, the only part where the form of the gun admitted the employment of this kind of strengthening."

The 2½-inch multicharge gun tested at Washington had wrought-iron bands shrunk over the pockets, while no bands were put on the chase. One of the forms of multicharge guns I have designed has a central tube and the balance of the gun is all "built up" by shrinking on bands. The built-up plan is therefore available for multicharge guns as well as for single charge, and they can be made equally strong. I do not, however, approve of built-up guns. I have much better and stronger plans. I have made these guns in many different ways. Captain Birnie has only seen one and is not therefore competent to judge.

The enormous penetration accomplished by the one-half-inch bore model I made excites the attention of Captain Birnie. That gun penetrated 10½ calibers in wrought iron and was not fully charged at that. The same gun can penetrate 12 calibers. It was made to prove that the multicharge system could be carried out to almost any extent. We do not propose to make large guns of as great relative power. If we did, a 12-inch gun would penetrate 12 feet of wrought iron. That is more than is necessary, and the gun would be very long. We can, however, with guns of moderate length, penetrate four or five calibers, or double as much as any single-charge gun can do, and with less pressure.

The power developed by the 6-inch multicharge gun at Sandy Hook exceeded anything ever before accomplished by any gun of that caliber, and with less pressure, as the official reports show.

With a multicharge gun, the breech of which can be made of the same material and as strong as any single-charge gun, the same charge of powder can be used in the breech if desired, and with the same effect. After that additional charges can be added and much greater results achieved.

Captain Birnie, on page 91, says the range of the 6-inch navy gun is 3,046 yards at an elevation of 3° 10′. The range of the 6-inch multicharge gun at Sandy Hook was 3,000 yards at an elevation of 2° 55′, using much less pressure than the naval gun.

The range of the Krupp 11-inch gun at 4° 54′ was 4,419 yards, weight of projectile 760 pounds, weight of powder 254 pounds. (See report "Board on Fortifications and other Defenses," p. 45.) The range of the 6-inch multicharge gun at 4° 30′ elevation was 4,480 yards. Sixty-one yards greater than the Krupp gun, with 24′ less elevation, and using a pressure of 10,000 pounds per square inch less than the Krupp gun.

Captain Birnie closes his remarks as follows: "Most emphatically, then, a higher energy has not been obtained with this gun with its successive charges and with moderate and safer pressures than can result from any gun of the same caliber using only one charge." That is the statement of Captain Birnie, who never witnessed an experiment with a multicharge gun. Against this I quote the statement of the Ordnance Board, composed of officers of the same corps, outranking Captain Birnie, and of much greater experience, who say in their official report on the multicharge gun trials: "There seems to be no doubt that a higher

energy has been obtained with this gun with its successive charges and with moderate and safer pressure than can result from any gun of the same caliber using only one charge."

(Signed) T. G. Baylor, *Colonel of Ordnance, President of Board.*
Geo. W. McKee, *Major of Ordnance.*
Charles Shaler, *Captain of Ordnance.*

Note.—For a more full and complete answer to all objections to the multicharge system, reference is made to a paper read before the "American Association for the Advancement of Science" on August 16, 1887, by J. R. Haskell, which has been printed in pamphlet form, and can be had free on application to Mr. Haskell.

Capt. Charles Shaler, *Ordnance Department.*

One point made in Captain Birnie's paper can not, I think, be too much dwelt upon.

Suppose that it is desirable to try a steel gun cast in a single piece, why should it be necessary to await the result of the trial before commencing to build guns equal to the best?

Nothing is more certainly proven with reference to guns than that each caliber must be tried for each different mode of construction. The history of gun trials is full of accounts of structures which have answered for a certain caliber and failed for a greater one.

If a 6-inch steel gun cast in one piece prove suitable after fabrication and trial, it will teach us but little as to higher calibers. The larger gun must be made and tried before similar ones can be issued to the service. All this requires in each case increased plant and more time for experiment.

The most powerful pieces in existence to-day are, without any question, built-up guns. A course of costly experiments extending through years has shown that for each caliber used the method is good. We know that such guns can be constructed if we obtain steel possessing certain characteristics declared by those who wish to supply the material in this country within limits that can be reached by them, because such material has been made in Germany, France, and England. There is no peradventure about this, no careful passing from the known to the unknown, no questions of relying on the statement of an expert that he can do what has never yet been done, but certainly because we may all possess a knowledge of what has already been done frequently. In other words, did the Government but possess the plant for fabrication it could at once commence to supply an armament to defend the coast.

We do not know positively that a single cast-steel gun will answer the purpose. It may do so, and if we are to wait until guns are made of all the materials proposed, the coast will never be armed. Cast steel made by the open-hearth, Bessemer, crucible, or mitis processes has been advocated; so has aluminum bronze; so has a mixture of the cheapest kind of pig iron "refined" by adding proper proportions of copper, lead, and mercury. Wire winding is urged, and so year by year will other metals and methods, good, bad, and indifferent, come up.

By all means let them be tried in some suitable way, but when we know to-day how to make guns equal to the best in existence, why continually delay their manufacture lest something else may prove better.

To do so is to imitate the poet's—" Fools waiting for certainty."

Lieut. E. M. Weaver, *Second Artillery.*

The gun *users* look at this question of gun *making* with a little impatience.

The gun makers in this country have been—as Captain Birnie's account shows—experimenting with this, that, and another gun design for a score of

years, working along cast-iron muzzle-loading lines, then cast-iron breech-loading lines, and have now settled down on what Captain Birnie regards as the ultimate stage of development, in so far as design is concerned, namely, the built-up forged-steel gun.

Captain Birnie's advocacy of the forged-steel gun is certainly as emphatic as it could well be; and in view of the clouds—small as yet, to be sure—on the horizon of the forged-steel built-up gun, as represented by the cast-steel gun, and the use of aluminum bronze as a gun metal, he is surely to be complimented on the frank manner in which he states his opinion, all the more so inasmuch as what he says will, per force, be accepted as the Ordnance view, notwithstanding the disclaimer in the preface.

The Artillery would be thankful if it could think that the end to temporizing in this matter had been reached; for if it ever come to be a fact, we may expect to have a few first-class guns mounted; but on looking back our confidence is impaired, for we recall the fact that there has from time to time, if not always, been some "cock-sure" idea advocated that has in due course retired before a new fancy.

During all this time the coast has been without protection from shelling, and the artillery has not had a single breechloader of larger caliber than a field gun for practice purposes, notwithstanding the fact that there were good breechloaders of all calibers needed for a secure defense on the coast *on the market*, and that there were several breechloaders at Sandy Hook, idle, that had been sufficiently tested for drill purposes, if not for firing, that, considering their breech mechanism alone, would have been a blessing as an object lesson to artillerymen who have never seen a breechloader as large as a siege gun.

Captain Birnie places the responsibility for all this at the door of Congress; but may it not be true that, if the Ordnance Department had been less interested in experiments, and more alive to what could have been had by other methods, Congress would have been more liberal?

It must be admitted that there has been no time within the period under consideration that we could not have *purchased* and mounted on our coasts guns that, for each epoch, would have protected our cities, and thus have given some return, in the form of insurance against loss of property, to the citizens who pay for the weapons. It seems to us the interest of the citizens of our sea ports in this matter demands that we *first give them protection, from whatever source or by whatever methods it can be secured*, and then, after having accomplished this, we may legitimately experiment with a view to developing home gun making.

On the basis of this home-manufacture policy our seacoast has been forced to await the development of the American idea in gun making, which has been, in practice, the Ordnance idea. And what is the result? A servile adoption of European ideas that might have been accepted twelve years ago, as clearly set forth in Commander Simpson's report of his official visit to Europe.

The conditions are not different to-day. There are several gun designs claiming attention, and our coasts are unprotected.

The guns we most need are those that will hold off the largest guns afloat to a point beyond shelling range from the city being defended. It is these large guns on our outside line of defense that will be needed within a hundred hours after a declaration of war. Such guns should have greater ballistic power than any gun that can be floated against them, and be able to pierce or shatter any armor that can be carried into our waterways. *It is economy to mount the largest guns that can be secured*, for the larger the gun the greater lead we shall have over armor in the pending race, and, by anticipating its development, our guns will be longer serviceable; also, since the effective range of guns

against armor increases very rapidly with increase of caliber, and the area guarded increases as the *square* of the effective range, larger guns mean *fewer* guns and *fewer* forts. Comparing, for the sake of illustration, a 20-inch with a 16-inch gun, the effective range of the former is seven times the latter; the area guarded effectively, forty-nine times. It certainly does not cost forty-nine times as much to mount a 20-inch gun as a 16-inch gun.

The necessity of large guns has been made imperative by the present and prospective strength of steel and compound armor; we believe that nothing below 1,500 foot-tons projectile energy per ton of plate can with safety be assumed as a measure of plate strength for ballistic estimates.

It will be years before such guns can be supplied, if we depend on past methods. The only way, it seems to us, to secure a speedy defense of the coast on the outside line is to *open contracts to all reputable gun makers of the world, regardless of design*, provided a reasonable safety of gun is guaranteed, with modern mechanical appliances. It makes little difference to citizens and artillerists whether a gun is or is not a few pounds heavier or feet longer than another gun, if it gives *proper ballistic results.*

It would be a calamity, we believe, if, to arm our outside line, we should be forced to wait for the gun makers of built-up forged-steel guns in this country to creep tentatively through the stages from the present 8-inch standard to those calibers absolutely necessary to defend our cities from shelling.

WILLIAM E. WOODBRIDGE, Esq.

I am compelled to say that the "built-up" gun finds more than a "rival" in the 9.2-inch Woolwich steel-wire gun, which has imparted to its projectile of 385.8 pounds a velocity of 2,560 feet per second. And this is not a finality in wire gun construction.

We need guns; and I would not, if I could, hinder the production of guns of the Vavasseur type. But we must not, for the sake of uniting in a voice of "no uncertain sound," conceal from ourselves the truth. While its structure is in great measure theoretically correct, the principles accepted point to a higher type. As yet practical proofs of the strength of the system are wanting. High pressures are studiously avoided. As yet, it must be said (I might quote good authority), "we are building our guns on hypotheses that have never been practically verified." Assembling the guns with the most correctly estimated shrinkages and under the minutest inspection does not so far test the soundness of the material, or its freedom from injurious initial strains, that it may not leave a hoop at the point of rupturing from its own tension or a tube with an undetected flaw of any magnitude not apparent upon the surface.

It is impossible to make here the corrections, and especially the additions to the statements of the paper concerning wire guns, which would be necessary to afford a basis for a full consideration of their merits. I add a few words, however. The 10-inch brazed wire gun was not originally intended or expected to be altogether suitable for a test, but (as a 9-inch) was intended "to give the necessary experience to the workmen to construct the 12-inch gun determined on." ("Ordnance Report," 1872, p. 176.)

The powder used in the last three rounds was known to be of especial violence. In the words of the board: "It burst into two parts just behind the trunnions under a powder pressure of about 80,000 pounds to the square inch measured by the Rodman gauge." Nothing invalidated the indication of the gauge employed. The rupture was in a plane of imperfect brazing. It should be noted that the rear portion of the gun actually withstood the enormous pressure. The only possible question as to the strength of the system was that of complete brazing, all reasonable doubt of which was negatived by a study of the experiment itself.

When a "built-up" gun shall finish its career with an equal exhibition of strength it will have acquired honors not yet won by any of the existing or departed.

As a correction of the views expressed on page 36, in the paragraph closing with lines in italics, I refer to the "Report of the Board on Heavy Ordnance," 1882, page 17.

I think it necessary to avow the opinion that questions of national armament, often as intricate as questions of law, may be better decided by a "full bench" than by a single judge, however competent and impartial.

No monopoly of qualification can be claimed for any department or profession. The author, who has made ample exhibition of his learning and acquaintance with the theories of Lamé and Clavarino, offers a convenient illustration of this statement, by an error which might be serious in practice, in treating theoretically of the increase of resistance derived from a lining tube—on pages 22 and 23. I can neither quote the text nor hint the correction here, but shall trust to the ability and candor of the author to make the correction.

I question whether the Army may prefer that the production of guns shall be wholly "intrusted to military men."

Benjamin Robins, "the father of scientific gunnery," was a civilian; so was Doctor Hutton, who followed up his work; and Count Rumford, who investigated the force of gunpowder; so also the first to measure its actual pressure in guns; the inventor of the expanding projectile; Treadwell, Benjamin Chambers, Doctor Gatling, Hotchkiss, Parsons, Vavasseur—a few from a long list.

In 1850 we had here the (actual) wire gun—Treadwell's excellent guns; the expanding projectile, proved to be superior in accuracy to any cluster of shots recorded in the Ordnance Department, superior in penetration, exploding by percussion, and Chambers' slotted-screw fermeture. There was needed not professional ordnance skill to perfect them (that is not always its tendency), but a competent tribunal to weigh their value. Such a tribunal, selected with the greater care, from military, naval, and civil life, would have been in the past, and, I judge, would in the future be of the greatest service.

I take this opportunity to declare my high appreciation of the services of officers of the Ordnance Department, their ability and character.

Capt. O. E. Michaelis, *Ordnance Department.*

Captain Birnie certainly merits our gratitude for doing so well what to him has been apparently a labor of love, presenting succinctly a résumé of ordnance progress in the United States since 1840. His presentation is clear and unbiased. His own decided predilections control only when bearing upon our latest official construction, the hooped steel-forged gun, and herein he certainly must be held excusable, for we may well say of him in connection with this gun "Quorum magna pars fui." The time limit assigned compels me to be brief, and hence my remarks can necessarily touch but few points, and must be, in addition, merely suggestive.

I rejoice to see that Captain Birnie does tardy justice to that wonderful man, Daniel Treadwell. Some fifteen years ago I had the privilege of examining some of his unpublished work, and I felt then that he was certainly a quarter of a century in advance of his time, and that his name is worthy to be associated with the names of Bomford, Dahlgren, and Rodman, great leaders of American ordnance progress.

In discussing the subject of initial tension, the experiments of Mr. G. Leverich, M. Am. Society of Civil Engineers, undertaken in 1875, while he was in charge of the construction of the Thompson gun, should not be forgotten. He was the

first to examine the tensions of successive concentric rings from interior to exterior. His work will soon, I hope, be accessible to all interested.

The hooped forged steel gun, so far as military authority can make it so, is at present the adopted model, and it is the duty of all navy and army experts to do everything in their power to make it a practical success.

Still this sense of duty can not affect the right of private judgment. Personally I do not believe in the French fermeture; the objections to it are well known and need not be iterated here.

Captain Birnie himself appears not to be its partisan, and I agree fully with him that in the present state of our metallurgical plants it is the only feasible closure for the adopted model of gun.

Further, I am an avowed enthusiastic believer in the thorough trial of steel-cast guns. I recommended it nearly five years ago, and my belief in its feasibility has strengthened year by year.

Krupp is the *cheval de battaille* of the opposers to the Government trial of great steel-cast guns. His array of 21,000 successful guns is showered upon us, until we are apparently buried beyond possibility of exhumation.

The side that calls him must abide by the *whole* testimony of the witness; there is a well-known legal maxim that applies.

The hooped forged-steel guns of which there has recently been question with us, differ from Krupp guns in material, principle of construction, and breech mechanism, and when Krupp guns are cited in support of our present construction, I can, with equal logic, cite, in support of my views, the thousands and thousands of successful cast guns.

Krupp uses crucible steel at present, awaiting the impending improvements in the open-hearth process, the only trustworthy homogeneous steel made—a result due to the crucibles being solely a melting pot and not a refining apparatus. Krupp does not make a *hooped* forged gun, in our sense—he makes *mantle* or *jacket* guns. His underlying principle is the entire removal of longitudinal strain from the gun tube. His field guns consist of but two parts, the tube and the mantle, which carries trunnions and fermeture. His latest constructions, the 40-centimeter monsters, are also *mantled* and *not* hooped. Krupp uses the wedge as a closure, carried independently of the gun body—we, the screw, necessarily seated, directly or indirectly, in the body.

The Krupp ingots for the 16-inch gun bodies weighed over 70 tons each—pretty fair-sized guns to start with.

I do not hesitate to announce my belief that the *main beneficial* effects of hammering such a mass of steel lie in *shaping* the metal. I further believe that whatever supposed improvement may be brought about in its physical condition under hammering is due to successive heating and reheating. I am fully convinced that steel can acquire all its mechanical properties without hammering, and that in the near future we shall see both hammer and press used simply as economical shapers.

I can not understand why there should be such opposition to the thorough trial of steel-cast guns. Dahlgren, Rodman, and Woodbridge guns have been tried at Government expense; why not then steel-cast guns, every step in whose fabrication, whatever be the outcome, would add invaluable knowledge to our metallurgical manipulations?

We are not without justifying data for our hopes of success. Steel is a curious alloy—every day develops new features in production and behavior. *All* cast guns have been successfully made and tested in Sweden. An 8.4-centimeter gun, Krupp model, tube and jacket both cast, has been fired over 2,000 rounds with charges weighing 3¼ pounds and projectiles 14¾ pounds, and not the slightest

enlargement of chamber is perceptible. The metal was 38 carbon, with an elastic limit and ultimate tenacity for the mantle of 53,700 and 100,200, for the tube, 73,500 and 121,000, which shows that by proper treatment cast specimens can be made to indicate any desired physical properties.

I fear I have already exceeded my time, and will therefore stop, merely iterating the wish that the authorities would lead this investigation of the practicability of casting steel guns, an investigation that would in nowise antagonize any present plans of gun construction, an investigation that would be of incalculable advantage to what promises to be the widespread art of steel founding.

R. H. THURSTON, Esq.

I do not think that I can add anything valuable to the mass of facts presented by Captain Birnie. It is a paper of such unusual extent and richness that it could hardly be expected that any engineer, not a specialist in that field, should be able to offer more than confirmatory sentiments in such parts of the subject he might be somewhat familiar with.

The necessity of instant action, and that on an enormous scale, in view of the exceedingly critical position to which the blindness of the General Government has reduced us, must, as it seems to me, be obvious to the most thoughtless and least patriotic of our citizens. I am not sure that it can be said just where all the responsibility lies, but I presume that it is mainly with the Appropriation Committees of Congress, and especially in the House of Representatives. However, that is not the vital matter at the moment; the first thing to be done is to render the nation safe against foreign foes at the earliest possible instant; and it seems tolerably evident that much must be done in educating our representative bodies up to a point from which they may be able to form some faint idea of the dangers to which they have exposed, and to which they are still exposing, their country. Once Congress is fully aware of the situation, it is probable that less will be said of a visionary "surplus" in the Treasury, and more of its expenditure in directions in which it, and more, should long ago have been placed—coast defense, army and navy material, and interior and frontier improvements. Should the business men of the country ever take active part in matters of national importance, and work hand in hand with the legislative bodies and with their natural advisers of the two branches of the service, we may cease to apprehend such dangers as now threaten us; but I fear not until then. It is at least a source of some comfort to find that our officers, in Army and Navy, are doing their part, however much our legislators may neglect their highest duty.

I find myself greatly interested in the paper under discussion, both as giving valuable and often new information and as representing the views of experienced and thinking officers in regard to the best materials and constructions of modern heavy guns. While recognizing the difficulties involved and the comparative imperfection of the familiar processes and apparatus used in the manufacture of large masses in steel, I have always had a strong conviction that that metal would completely displace iron in all ordnance, as well as in nearly all constructions of other sorts; and, further, that ways would sooner or later be found to handle it in the largest masses that might be called for and to give it its highest qualities whatever their magnitude. We evidently are still a long way from the ideal state of the art to which we aspire; but we are as evidently making continuous and somewhat rapid progress. The built-up gun must obviously precede the solid in heavy ordnance; and the approach to the ideal construction seems to me, in the light of existing knowledge and experience, to be likely to come rather through the gradual increase in size and

decrease in number of parts of the built-up gun than through the—in some respects—opposite course illustrated by Treadwell and Woodbridge. It would, however, be folly to dogmatize in that, as in any other matter of engineering. The built-up gun is certainly to-day the representative of the highest modern art in ordnance construction. The introduction of oil hardening and tempering is an enormous step in advance; and the systematic ways now in vogue of testing, experimenting, and scientifically determining the quality of the metal, as variously treated, and of ascertaining the line in which further progress must be made, are sure to give us safe and sure guidance. The history of this progress, as presented by Captain Birnie, is an exceedingly interesting one, valuable not only as a record of the past, but as guide for the future. In the light of these systematically collected and arranged masses of knowledge, such as are here illustrated, it is to be hoped and fully expected that we may in time come to the construction of the heaviest of ordnance in single masses, or in few pieces, in such manner as to bring out the very highest possible qualities of metal in the best possible gun.

I have no doubt that the same succession of replacements of one construction by another which has sent the old Rodman cast-iron gun into limbo and has already sent the wrought-iron built-up gun after it will in time dispose of the steel built-up gun in precisely the same manner; but there is at the same time no doubt to my mind that for heavy ordnance, such as we are now accustomed to see adopted for the more important coast defenses and heavier iron-clads of the day, the steel built-up forged gun represents the best existing system. I agree heartily with the writer of the paper, as must every good citizen, that the industry of making such guns should be fostered in this country, even at the expense of large sacrifices by our taxpayers. This is a matter of simple self-protection and insurance. One of the great dangers constantly threatening our nation is that which comes of its persistent and criminal neglect to take the most ordinary of precautions in self-protection against foreign possible enemies among nations which have no such commercial interests to guarantee a peaceful disposition as has, for example, our own mother country. Once we have the material required for the manufacture of good guns, and establishments capable of turning them out in large numbers, we have improved our chances of preserving the peace and of securing respectful consideration of our rights and interests on the part of other nations enormously. It will probably be admitted on all sides that the United States Government is not called upon, by motives of either statecraft, business, or simple, wise provision of possible disputes with other nations, to do more than to institute effective means of self-defense; but it is probably quite as generally recognized as the part of wisdom to make our defenses against any possible foreign aggression as absolutely safe as our knowledge, skill, and wealth will allow. In this, as in most matters of business, the best preparation and the best material are the cheapest in the end.

Finally, in regard to the Treadwell and other systems of wire-wound guns, it may be said that, while their theory is unquestionably in many respects correct and somewhat promising, we have, so far as I am aware, no evidence indicating that the universally recognized practical difficulties to be overcome in their manufacture and use are likely soon to be satisfactorily disposed of. As to steel-cast guns, I have no doubt that they will come into use, but it will be first necessary to insure that they do not represent the conditions enunciated by Captain Birnie, and their advocates must be able to do more than assert that "steel in a relatively weak condition is abundantly strong for the work required of a gun." We—for, with this qualification, I am one of those advocates—must first find means of securing greater resilience of mass per pound weight in that gun than in the built-up gun. I think that in time the Whitworth and

Dean, or other processes or combination of processes, will bring about this desirable state of the art of great gun manufacture. With regard to the metal, it may be said that no form of iron, steel, or other metal is "strong enough" and tough enough for ordnance if we can, by any possibility, find another which is, in the mass, stronger, whatever the material and however put together. A nation on the defensive may not need many guns; but that is all the better reason for insisting that those which are supplied shall be the representatives of the highest skill the world can offer.

It is a singular fact that while nearly every great inventor in this field is an American, trained in the school of the American mechanic and encouraged by the grandly successful patent system of this country, they are all, invariably, compelled to seek the reward of their industry, skill, ingenuity, and persistence among the nations of Europe and among peoples who have never known the advantages of this form of protection of home industry. It is to be hoped by every good citizen that after a time, when the National Legislature shall have awakened from its Rip Van Winkle slumber—if meantime some powerful foe has not demolished our mock defenses and, like Prussia after the last Franco-German war, inflicted a fine that shall cripple us completely—our inventors and our long-suffering army and navy officers may see some slight attempt made to at once secure for the country an insurance against such dangers and a reward for their patriotic and earnest endeavors.

JAMES E. HOWARD, Esq., Watertown Arsenal.

In the construction of modern forged steel guns, a superior metal is employed which combines high elastic properties and tensile strength with a very considerable amount of toughness, together with homogeneity and soundness of structure.

This gun steel occupies an intermediate position in degree of hardness between the mild structural steels and the higher grades of spring and tool steels. Very elaborate tests of quality here have been made, which serve to establish its reliability, and the thorough method of inspection employed identifies and secures the acceptance of metal of the high standard of excellence which has been attained. The requirements of a gun metal are necessarily severe; a certain strength it must have, and it should have ample strength to compete on even terms with any weapons which may be encountered; in other words, only the best metal for the purpose should be employed.

The metal adopted in the construction of modern forged-steel guns seems to possess in the aggregate the greatest number of desirable qualities now attainable.

To review briefly the physical properties, mild steels approach in qualities the best grades of refined wrought iron; they are low in elastic limit and tensile strength, but possess great toughness, as shown by the elongation of the metal before rupture and by its contraction in area at the place of rupture.

Manipulation, cold, will elevate the elastic limit and tensile strength, but at the same time detracts from its toughness.

This method of increasing its resistance is limited in its application practically to a number of simpler forms into which the metal may be put.

Mild steel is slightly affected, comparatively, by surface defects of limited extent, such as indentations from hammer blows or cutting tools and the like, the relative influence of such defects increasing in serious importance with the increase in hardness of the steel.

The relative deleterious effects of interior defects of structure, such as may exist, in different grades of metal are very difficult of ascertainment, such information coming incidentally with a large experience in working the several

metals under a variety of circumstances. This much may be said, however, that instances have been met wherein the very softest steels have suddenly fractured with a display of brittleness unsurpassed by the higher grades of steel. No steel which has been improperly treated seems to be exempt from this behavior, and investigations have shown pretty clearly what is proper and what is improper treatment. These remarks have reference to the mechanical treatment of steel apart from questions of chemical composition. As we advance to the higher grades of metal, higher elastic limits and tensile strength are found with less elongation and contraction of area.

Gun steel is characterized by its high elastic limit and tensile strength, combined with an extraordinary degree of toughness.

The modulus of elasticity has been found to remain substantially the same in steels extending over a wide range in chemical composition and not to be sensibly different in tempered and annealed bars, hot rolled and cold rolled bars.

A reduction in the modulus of elasticity follows overstraining, but this has been found transitory in all specimens thus far examined.

Under higher temperatures there is a reduction in the modulus of elasticity, the reduction going on as the temperature increases, the practical effect of which in a gun would seem to be the introduction of the principle of "varying elasticity" while the gun had a temperature at the bore higher than at the exterior.

While the elastic limit is lower than at atmospheric temperatures, yet the tensile strength, after showing a slight reduction in the vicinity of 250° F., increases from this temperature or thereabouts until at 500° to 600° F. the increase in strength amounts to from 15 to 20 per cent of its strength cold.

It has been further observed that bars which have been strained while at these higher temperatures by loads in excess of the strength cold were not thereby weakened when afterwards tested to rupture at atmospheric temperatures, but, on the other hand, were found to retain the strength due to the high temperatures at which they had previously been strained.

The coefficient of expansion by heat appears to be influenced by the chemical composition of the steel.

A series of observations made on steel bars, ranging in carbon from 0.10 per cent to 1 per cent, the other elements present not varying in regular succession, showed a progressive reduction in the coefficient of expansion as the percentage of carbon increased.

The mild steels showing about the same rate of expansion as wrought iron, the hard steels not reaching quite so low a coefficient as that of cast iron, but cast iron contains a much larger amount of carbon than the highest steels experimented upon.

Internal strains may exist in steels and other metals. They are an advantage in guns when disposed according to certain laws governing the resistance of cylinders.

When they exist locally and of great intensity, they become correspondingly disadvantageous and may cause unexpected fracture of the metal.

The intensity of such strains is limited by the elastic limit of the metal, and treatment that elevates the elastic limit thereby increases the capacity for receiving internal strains.

The introduction of internal strains in well-annealed metal depends upon, at least in a measure, changes in density, and to effect a permanent change of density by cold treatment necessitates a permanent set or flow of the metal, from which it follows that the higher the elastic limit the more difficult will it be to introduce internal strains by the application of external stresses.

The advantages which high grades of steel possess in the direction just referred to are not known to be offset by counter disadvantages resulting from moderate changes in temperature.

Commander R. D. EVANS, *U. S. Navy*.

One can only speak in terms of the highest praise of this excellent article, and had I the time to do so I would like to place myself properly on record with reference to the matter of "steel-cast" guns. I have for many years advocated the steel-cast gun and firmly believe that it will prove the gun of the future, but, at the same time, I would not in any way interfere with or defer the making of built-up guns, which we have reason to know are good. There seems to me to be ample room for both systems, and I hope the great industry of steel casting may have proper encouragement.

Capt. JOHN G. BUTLER, *Ordnance Department*.

As it is perhaps true that, after Mr. William P. Hunt, I am chiefly responsible for the existence of the 12-inch breech-loading gun at Sandy Hook, it may follow that I am qualified to speak upon that part of Captain Birnie's able paper devoted to cast-iron guns. But since the practical attainment of my own wishes in the successful efforts of Mr. Hunt before the Logan committee, it has been rather as "a looker-on in Vienna" that I have interested myself in the gun question, and I am somewhat averse to entering the arena of discussion. Nevertheless, as I think that the prejudices of the author of "Gun-Making" have stood a little in his way as a fair historian, I will undertake to correct two or three of his statements, although I fear that it will be impossible to confine my remarks within the limits which you find it necessary to assign to the discussion.

Captain Birnie is certainly the first ordnance officer who ever found anything to admire in the report of the Select Committee on Ordnance, 1869. This committee announced a number of conclusions. Among them was one condemning the Rodman, Dahlgren, and Parrott "systems" as applied to rifles, and this he considers so powerful a backing to his argument that he exults over it more than once, and overlooks another conclusion of the committee condemning all European "systems" as showing "no exemption from the rule of failure," and discountenancing their trial in this country. The committee in no place condemned cast iron or cast-iron guns per se, as Captain Birnie seems to think, but its report was made to do duty last winter in parading before Senators and Representatives lists of Rodman, Dahlgren, and Parrott rifles which had failed, carefully suppressing the fine records of many of these guns and making no mention of well-known causes of failure in others.

The argument for the fair trial of strong cast iron as a material for heavy rifles was largely based upon the admirable performance of many cast-iron guns and the brutal treatment, by vicious systems of projectiles and rifling, which seemed to justify the failure of others. It has, perhaps, "suited the interests" of the friends of cast iron to call attention to its record just as it now appears to "suit the interests" of Captain Birnie to discredit that record and place his individual opinion against the judgment of men who formed theirs at the proof butts. Many officers of distinction witnessed these experiments more than twenty years ago, while the author of "Gun-Making" was employed elsewhere. The enormous strains to which the guns of that day were subjected were not theoretical; the facts were there for observation. The then Chief of Ordnance, General Dyer, fifteen years ago ordered a discontinuance of his own soft-base projectile and directed the use of the Butler projectile in experiments with powder then going on. Krupp shortly after abandoned his lead-jacketed projectiles, eccentric chamber, and narrowing grooves—a system which had hitherto restricted his guns to the use of comparatively light charges—and adopted the copper-banded projectile—and lo! the result at Meppen in 1878. The English about the same time abandoned their studded projectiles and took up the

expanding system for their muzzle-loaders, and it is a perfectly noteworthy fact that from the adoption of reliable muzzle-loading and breech-loading projectiles it has all been smooth sailing for the development of guns and powders, the pressures having been brought practically under control.

Captain Birnie is not more fortunate, I think, in ascribing the heavy pressures formerly recorded to "defective means of measurement" or inexperience with the Rodman gauge. The exterior gauge was rarely used; the interior gauge had been used for years; the same officer (Colonel Baylor), who used it at Fort Monroe, afterwards used it for years at Sandy Hook, and his experience with this gauge and various ballistic instruments was larger than that of any officer in this or perhaps any service. Again, the very same employee—Hickey—who had prepared the gauge for years at Fort Monroe, both for Army and Navy experiments, was afterwards employed at Sandy Hook in setting up the same instrument, and is probably thus employed at the present time. In regard to the few indications of pressure supposed to exceed that due to the explosion of gunpowder when confined within its own volume, it is possible that when this high limit has been approximated in the gun intense local action has interfered with the normal action of the gauge.

I think I must mention one instance of Captain Birnie's inconsistency in his opinion that the "true reason" for the bursting of cast-iron guns was "the frailty of the guns themselves," and in his emphatic "opinion" that bad projectiles and rifling had little to do with it. I refer to his own citation of experiments at Nut Island with 15-inch guns rifled with two grooves. He says: "As an illustration of what *cast-iron rifles* [a] will stand when *badly treated* (thereby implying that they had not heretofore been "badly treated") we may extract the *four guns of this class* [a] (conveying the impression that they were "cast-iron rifles" in an ordinary sense) which were included in Wiard's somewhat notorious experiments at Nut Island in 1873–1875," and he then cites these so-called "rifles" which burst at the nineteenth, second, and seventh rounds, respectively, with charges of from 100 to 140 pounds of powder. Now, if the Wiard projectiles did not burst these guns, how is their failure at the very outset of the firing to be accounted for, in view of what Captain Birnie calls elsewhere "the present efficiency of the 15-inch guns with increased charges?" If, on the other hand, the projectiles *did* burst the guns (if I may venture upon so rash an hypothesis) his citation is inconsistent with the position which he has chosen to take on the question. Even his qualifying admission that "The Wiard rifles are generally admitted to have been destroyed by excessive charges and bad projectiles" he can not bear to let stand, and therefore adds: "Yet the charges he used bear no comparison with those now required to be used in steel guns." Very true, neither in quantity, which he refers to, nor in *quality*, which he does not. Nor do they bear comparison with the 265-pound charges of the 12-inch cast-iron rifle; but how much over 100 pounds of powder, bottled up in the bore, or operating behind a projectile which acts as a wedge, does Captain Birnie consider necessary to burst a gun?

The concluding paragraph of the chapter on the cast-iron rifle touches me personally, and not very generously, and as the statements are entirely erroneous and have appeared in newspapers, it is perhaps as well to at least notice them. The paragraph covers a considerable portion of the history of the case, and I beg to quote it entire:

"The ability which the officers of the Ordnance Department have shown in designing so powerful a cast-iron rifle as the one lately proved is an earnest of their desire and capacity to carry out whatever Congress may direct. Had the

[a] Italics marked are mine.

12-inch cast-iron rifle been made after a design presented to the Logan committee, that was, to fire 150 pounds of powder with 700-pound shot, and give a muzzle energy of but 10,000 foot-tons, instead of the 17,000 foot-tons procured in the design actually used—but little interest would attach to a discussion of its merits here or elsewhere."

Briefly, and perhaps flatly, I will say that I designed this and other of Mr. Hunt's guns which were before the committee, and that the design has been adhered to in good faith by the Chief of Ordnance. In the light of many months' later experience a few changes were made by the Ordnance Office, with this difference in our judgment, that, whereas, the only change of moment (enlarging the chamber), which was made *before* initial proof, I would have made *later on* and did anticipate and provide for three years previously.

I first urged for the trial of a 12-inch cast-iron rifle about fifteen years ago, before the Heavy Gun Board of 1872, and on subsequent occasions have continued to argue that such a gun should be tested under the modern conditions of improved powder and projectiles. In 1881 my friend Mr. Hunt and myself, being nearly of one mind on the subject, I assisted him in the preparation of his case for presentation to the Getty Board upon two conditions, namely: That he should make no acknowledgement of my services (for one reason, that I did not wish to appear before any committees), and that I should receive no pecuniary compensation from his company. He urged before that board a 12-inch breech-loading cast-iron rifle ("D") to be tested in comparison with the four 12-inch B. L. rifles then under contract for the Government, but subsequently abandoned. Following this design ("D") were two other ("E") and ("F") exactly similar in outline and dimensions to the cast-iron rifle, but differing from each other in that one was lined with a short steel tube and the other was hooped with steel. This Gun Board of 1881–82—with the exception of the two ordnance officers—became badly afflicted with the steel-wire craze, and its report was not fully concurred in. The Logan committee was appointed, and before it Mr. Hunt and others laid their plans. The cast-iron rifles designs "D" and "F" were to be cast breech up, for reasons given; they had the Rodman contour as far as the breech, a slight portion of which only was cylindrical so as to conform to that outline which was most economical and convenient for the hooped gun "F." A few inches of taper on the base of design "D"—a question of taste, not utility—gives the curve of the gun at Sandy Hook. In all designs for cast-iron guns, whether entirely of that metal or steel-hooped, I introduced the feature of a *steel sleeve*, or *housing*, for the slotted screw breechblock, so as to avoid cutting away half of the cast-iron thread, a feature which has been retained. The character of the pitch was that which I had urged for many years, now widely adopted, i. e., an increasing pitch in which the angle at the breech bears a reasonable relation to that at the muzzle. I provided for fewer grooves and an expanding projectile, because at the time it was thought easier on the gun. The character of the rifling was otherwise practically retained, the angle being slightly changed, but as 3 or 4 feet were added to the muzzle—which Mr. Hunt would probably have added without suggestion—I suppose that this little end of the gun was not considered Mr. Hunt's property, and so in it there is a sudden return to the old love and the pitch made uniform for about 3 feet.

The test of these guns was especially urged (pp. viii, 79, 80, Hunt) as serving to determine: 1. Whether a serviceable heavy breech-loading rifle could be made of cast iron pure and simple. 2. The extent to which steel as an auxiliary might be beneficial. 3. Whether it would be better to apply the steel inside as a tube or outside as a jacket—the latter plan being the more expensive. The report of the Logan committee was concurred in by Congress, and among the

guns appropriated for were two cast-iron 12-inch breech-loading rifles and one cast-iron rifle banded or hooped with steel. As these guns had been urged, I believe, by Mr. Hunt alone—the ordnance office favoring only the all-steel and the French systems—it was considered that the three guns thus designated meant Mr. Hunt's, and as it was thought that the committee had intended to add the words "one to be lined with a steel tube," after the words "two 12-inch cast-iron rifles," etc., Mr. Hunt suggested and obtained authority to put a steel tube in one of them. I have seen this circumstance referred to as though it marked some lack of confidence on Mr. Hunt's part in the cast-iron gun, and therefore deem it proper to say that he made the request at my written solicitation. The argument for the test of the series of guns ("D," cast-iron; "E," cast-iron lined; "F," cast-iron banded) was logically sound; my own arguments on professional grounds fitted into his from a manufacturer's standpoint; we had worked hard to get the guns and succeeded. I believe that on his own account Mr. Hunt would have preferred the two cast-iron guns intact, but he cheerfully made the concession to me.

This gun was not originally designed to fire "but 150 pounds of powder." Mr. Hunt was willing to guarantee such a charge, or 10,000 foot-tons energy, and this being at the time well up to the standard for *service* guns of like caliber abroad, he argued that the proof of the gun should be *commenced* with that charge. But the identical figures (17,000 foot-tons) which Captain Birnie now gives great credit for in another quarter was provided for as a contingent proof for this gun as far back as July, 1881 (p. 33, Hunt). True, the charge of 225 pounds of powder then provided for might not have quite accomplished this result, but it was never pretended to accurately determine the *chambers* of any of the guns until working drawings were required, and it was a year or two after the appropriation for this rifle, and *three* years after the charge of 225 pounds was suggested to the Getty Board, that the dimensions of the chamber were finally fixed. This hardly constituted a "design," and it will also be admitted, perhaps, that adding a little to the muzzle of a gun *originating with and produced by others*, or making it exactly of ½-inch greater semi-diameter at the breech, or adopting a slight change, or, in fact, any change of rifling, is not designing a gun in any rational sense. Furthermore, I claim that these changes were not dictated by the best judgment. Mr. Hunt's programme was to begin proof with charges giving, say, 10,000 foot-tons energy, which, if sustained up to a certain number of rounds (100 rounds *were guaranteed*), would by our agreement, which appeared to satisfy the committee, justify the construction of this cheap gun. After this the chamber would have been reamed up to hold the 225 pounds specified, and after further proof we could ultimately reach 270 pounds, and perhaps 300 pounds of powder and 800-pound shot, with which charge the proof could have been continued. This would have left the chamber in perfect condition for the heavier charges. It was not a well-ordered experiment to jump at once for the maximum effect. What was wanted was the true measure of the gun's strength or weakness, and this would not give it; our programme would have developed the same power, but I think more wisely, and the proof of the gun would have been further and more intelligently advanced. I think, therefore, that Captain Birnie is mistaken in claiming for "the officers of the Ordnance Department"—whether this means himself or coadjutors—any credit for "designing" what he is pleased to call "so powerful a cast-iron rifle as the one lately proved." One would suppose that he would hesitate before putting himself or friends into the peculiar position of first energetically opposing the construction of a gun and afterwards claiming credit for all there was in it. Mr. Hunt as the manufacturer, and I as the designer, and both of us as the originators of the 12-inch breech-loading

cast-iron rifle, have to thank the Messrs. Du Pont for an excellent powder, and there our obligation ends.

Another important contingency was provided for in connection with heavy cast-iron guns. The admirable conservation of the bores of cast-iron rifles had been observed, but with improvement in gunpowders the tendency would be to increase of charge and weight of shot, and under the longer sustained heat and action of the powder gases it was possible that the surface of the chamber and of its junction with the bore might need protection. I therefore revived an idea which occurred to me several years previously at Fort Monroe, upon examining the bottom of the bore of a gun which had been fired many times, and suggested—as referred to in Mr. Hunt's letters to the Getty Board, page 49—a chamber lining of thin steel or copper, which would be removable at pleasure. I think the chamber of the 12-inch gun should now be reamed up and this thin steel-lining tube inserted. It has nothing to do with the strength of the structure and is now thought advisable, I believe, in heavy steel guns. Had the chamber of this gun been made smaller in the first place a beautiful new surface could have been presented for every one or two hundred rounds of increasing proof charges.

For the rest, although I believe that the character of many of our harbors and the enormous extent of our coast, combined with our grievous necessities, should long since have prompted the definite settlement of the question how far cast iron may be available for heavy coast guns, yet I am in hearty accord with all efforts looking to the development of gun-steel industries and to the highest type of the steel gun. Captain Birnie presents one of the ablest arguments in this direction that has come to my notice, and although much that he says is already familiar to ordnance officers—in part by his own excellent professional work—yet I have read his paper with fresh interest and profit. Nor is any apology necessary, in my opinion, for past failures; the Government is rich enough to support experiment. The material is here, and if it needs improvement, the metal workers are here to accomplish it. The mechanical part of the problem is small, the "designing" is still less; the metallurgist will create the "gun of the future." But I believe that a "high-power gun" should mean a *high-pressure gun* (the variety of our powders is becoming too complicated). We do not want a tube as long as the moral law, begging for easy treatment by the powder, but a shorter, more compact, and more convenient weapon. "High-power ammunition" would be much more appropriate expression at the present time, for to the powder manufacturer is really due most of the credit now so complacently absorbed by the gun exponents. Rodman is occasionally named as a man well enough in his day, but I rarely see the name of Du Pont mentioned.

Lieut. WILLIAM CROZIER, *Ordnance Department.*

Progress is the movement in the mechanical arts, traveling the parallel roads of increased economy and increased efficiency.

A fixed belief in the excellence and serviceability of a type of mechanical construction, while supplying the confidence necessary for engaging in its extensive reproduction, is not incompatible with investigation as to the lines of possible improvement.

The lecturer has stated his appreciation of this fact, and while urging the manufacture of the built-up forged-steel gun, a satisfactory and now undoubtedly the best type, has had a not discouraging word for the two most prominent attempted improvements under trial, viz, the steel-cast gun and the wire gun. With reference to the former he has indicated very clearly the requirements, the difficulty of attaining them, and the results of falling short of them.

I will call attention only to the fact that the progress attempted to be realized in this effort is in the direction of economy only, the less important of the two roads; and that, as far as efficiency is concerned, its advocates, while claiming in general terms that it will be as great as in the built-up guns, practically concede in their specifications that it will be less; making, therefore, a step backward in this direction.

The almost universal law of progress is that it is from the simple to the complex; improvement in material and combination overcoming the disadvantage of complexity, and increased expense being more than compensated for by increased efficiency. A return to simplicity for simplicity's sake at a sacrifice of efficiency is rare indeed in the arts.

I will now try to indicate briefly what constitutes the promise of the wire gun, what are the difficulties in the way of the fulfillment of the promise, and what the probable lines along which the difficulties may be overcome. The main object sought to be attained in wire guns is great tangential resistance without corresponding sacrifice in other directions. The desirability of this object may be explained as follows:

MM. Sebert and Hugoniot have established for the pressure on the base of the projectile the formula

$$P = P_0 \frac{W^*}{W + \frac{c}{2}}$$

in which P_0 is the pressure at the breech, W is the weight of the projectile, and C that of the charge. The energy of the projectile is

$$\frac{Wv^2}{2g} = \int Pdx = \frac{W}{W + \frac{c}{2}} \int P_0dx.$$

If we take the axis of the piece as the axis of abscissas and plat the pressure curve the expression $\int P_0dx$ will represent the area under this curve, to which area, therefore, the energy of the projectile is proportional.

If the strength of the gun permitted the use of a kind of powder or method of forcing for the projectile (or both) such that the combustion of the charge should be completed before the movement of the projectile commenced, the pressure with the stated charge of 100 pounds and density of loading .9, would rise at once to 33.6 tons and fall off to 4 tons at the muzzle, instead of rising to 16 tons after a movement of one and one-half calibers and falling to 2.9 tons, as indicated in the plate accompanying the lecturer's paper. The area under the pressure curve would be increased about one-third, which represents the proportion of gain. But with sufficient strength we are not limited to the use of a charge of 100 pounds and density of loading .9. There can be put into the chamber of the 8-inch breech-loading steel rifle a quantity of powder sufficient to give a density of loading about 1.15, with which charge and the condition of complete combustion before movement the pressure would rise to about 45 tons and drop to 5.34 tons at the muzzle,[a] more than doubling the

*Etude des Effects de la Poudre, by H. Sebert, Lieut. Col. de l'art de la Marine et Hugoniot, Capitaine de l'art de la Marine.

[a] The pressures are computed by the formula of Messrs. Noble and Abel.

$$P_0 = 43 \left(\frac{.43}{v-.57}\right)^{1.057}$$

in which P_0 is the pressure per square inch and v is the ratio of the volume occupied by a weight of water equaling that of the charge to the volume occupied by the products of combustion.

Researches on Explosives by Captain Noble and F. A. Abel, No. II.

area under the pressure curve. Hence the energy imparted to the projectile would be more than double that under present conditions. The weight of the projectile remaining the same, the velocity would be increased to one and one-half times the present, or to 2,737 feet per second.

The gain from increased strength of construction is apparent. These conditions can probably never be fully attained in practice, but subdivision of the grains and the law that the rate of combustion is proportional to the pressure, together with our ability to increase the severity of the forcing, are means by which we can reach a very close approximation to them. That severity of forcing increases and does not diminish. As has been stated, the energy of the projectile is not only apparent from theoretical considerations, but has been proved by experiments made with that object by Messrs. Noble and Abel and by MM. Sebert and Hugoniot.

Other considerations than that of tangential resistance of course enter, such as erosion, limiting the useful pressure. I am only endeavoring to indicate the limit toward which we may strive.

The difficulty of longitudinal resistance in wire guns is one with which all are familiar. Various methods have been devised for overcoming it. They can be divided into three general classes—those which place the resisting member within the wire coil; those which place it without, and that of Doctor Woodbridge, which brazes the wire coil into a solid mass.

But the difficulties of attaining, even theoretically, the high tangential resistance claimed by most of its advocates for the wire construction is not so generally understood. Misapprehension upon this point has been fostered by the assumption of unattained and unattainable values for the physical constants in cast iron and steel[a] and by their declining to be governed by the rule, so strictly observed by the designers of built-up guns, that no part of the structure shall be strained beyond the elastic limit of its material, either at rest or under fire.

If the tube, which necessarily forms the core in all systems of wire construction, is to be subjected to this law, then a wire gun can, in general, be made no stronger than a built-up one of the same thickness. For the formula

$$P_0 = \frac{3(R_1^2 - R_0^2)}{4R_1^2 + 2R_0^2}(\rho + \theta)$$

(see p. 99 of the printed lecture) giving, as it does, the admissible powder pressure, under the supposition that the metal at the surface of the bore undergoes a range of dilation from the elastic limit of tangential compression at rest to that of tangential extension under fire, applies equally to built-up and to wire guns.

We must disabuse our minds of the error, likely to find hasty lodgment there, that the wire affords a more rigid support to the tube than surrounding parts of forged steel do. The rigidity of this support depends upon the modulus of elasticity of the supporting material, and that for steel wire is no greater than for forged steel.

The wire used in the construction of the guns at the Watertown Arsenal had about 2,000,000 pounds less modulus than the forged steel used in gun construction, although this wire had an elastic limit of 100,000 pounds and a tensile strength of 170,000 pounds per square inch.

The extreme range of the metal of the bore being obtainable in a built-up gun of four concentric cylinders, we can go no further either by greater sub-

[a] I do not refer to the elastic limit of the steel wire; that has been generally understated.

division or by increased strength of surrounding parts. The limit of the play of the tube prevents the utilization of the great elastic strength of the wire. Possible improvement lies either in such treatment of the tube that its elastic limit may be raised at the expense of other qualities considered essential in the built-up gun, or in partial emancipation from the law of elastic overstrain. The tube may be made very thin and its office reduced to that of a mere core for the winding and medium for carrying the rifling. All that may be required of it is that it shall stay in its place, affording no assistance to the strength of the structure, which is amply secured by the wire.

Whether or not under these conditions the tube will remain intact when subjected to alternating strains greater than its elastic limit is a matter to be decided by experiment. Those of Woehler and Bauschinger indicate that if strained without support through a range much greater than the elastic extension in one direction only, it would ultimately give way. What would be the result if supported by an envelope with a large reserve of strength is unknown; but the superior ability of the wire to hold it together after it has ceased to afford any assistance itself furnishes the hope of the ultimate, though perhaps slowly progressing, substitution of wire for a part of the forged-steel envelope.

The indications are that the art of gun making has so far approached a science that future improvement will be a growth, and that the day of radical new departures is passed.

Capt. Rogers Birnie, *Ordnance Department.*

In closing this discussion the lecturer wishes first to remark that his advocacy of the built-up forged-steel gun is based upon the belief that it is preeminently the gun of the present; also that it is a good gun, and if a seacoast armament is to be provided, the present development of this system of construction affords an opportunity for going to work at once. Experiments are costly and tedious, and may be made unending. When once a satisfactory degree of excellence has been reached the results should be made available. No one will pretend to say that this gun of to-day is the ultimatum of science, or that experiments and tests of promising systems should be discontinued. I am not opposed to tests of steel-cast guns, but hope they will be sufficiently tested to establish their true status. The argument is directed chiefly against the delay and procrastination which must be ever present with us if we continue to defer making guns in quantity so long as plausible designs continue to be put forward.

The lecturer finds many points of agreement with Major Campbell in his admiration for the grand civil establishments that exist in other countries for the manufacture of ordnance, but it will scarcely be denied that each of these establishments is provided with a special corps of ordnance designers and manufacturers, and that such men are the more valuable in proportion to their experience. Equally so is it necessary to have an experienced and trained body of officers, who may intelligently represent the interests of the Government. In every country officers are especially assigned to such duties, whether by one designation or another, and I believe that an organization of this kind is the more effective and useful in proportion as its personnel is able to devote the most exclusive attention to its special duties. Knowing full well the devotion to duty which actuates Major Campbell himself, I must ask him to credit the same spirit to others of his profession, and disabuse his mind of the suspicion that in any path of duty their existence is or can be "equally comfortable in failure or success." The number of mixed boards that have been appointed in late years to control questions of armament, and even the designs of the guns to be manufactured, does not permit one to say that any special corps has controlled the

question. So far as contemporaneous records teach us, the policy of the Government is to encourage both the making of steel and the fabrication of guns by private manufacturers.

The lecturer must dissent entirely from the view advanced by Doctor Woodbridge, that dangerous initial strains will be found in gun hoops of steel as now manufactured in this country. Careful experiments have proved that no initial strains existed in a hoop taken from the ordinary run of manufacture, and there is otherwise no proof of their existence; on the contrary, the actual firing tests of many hooped guns and extended experiments show that the hoops, which are carefully inspected before acceptance, are uniformly reliable.

The objection which Doctor Woodbridge makes to the statement referred to on pages 22 and 23 appears to be based on a curious misapprehension of the meaning of the word "inert" as used in the text. The nearest approach to the "inert" lining tube that we have in practice is that of a split tube. Such a case is exemplified in the experimental 8-inch rifle converted from a 10-inch Rodman gun by lining with a steel tube, breech insertion. (See table, p. 26.) The gun endured 281 rounds after the tube was cracked. The theoretically inert tube—that is, inactive as regards tangential resistance, which is the plain meaning of the text—is one conceived to be divided longitudinally by any number of meridian planes.

It is a pleasure to discuss the able and pertinent criticism in regard to "range of elasticity" contributed by Mr. Cooper. The comparatively small amount of knowledge that exists on this subject certainly ought to be enlarged by extended experiments. The lecturer does not hesitate to admit the force of this criticism in the sense that he has neglected to take into account the laws indicated by Woehler's and Bauschinger's experiments: That there exists a "range of elasticity" under incessant changes of strain which, probably for all metals, is less than the sum $(\rho+\theta)$. In practice, however, a number of compensations occur which must be considered. Taking the example quoted in Appendix B, for instance, it is stated, page 100, that the theoretically safe pressure for the gun is 38,710 pounds, for which the range of elasticity is expressed nearly by the sum $\rho+\theta$ [a] $=40,000+17,067=57,068$ pounds, instead of 75,000 or 80,000. This results from the direct application of the formulas, and is indicative of the average result. In another view of the case it seems reasonable to assume that the range of elasticity deduced from experiments like Woehler's may be increased in a built-up gun structure. The gun is not subjected to incessant changes of strain repeated millions of times, but to a relatively small number of changes repeated at intervals; and further, in the whole of the structure there is only a zone of metal near the bore of tube which is subjected to a range that would in cases exceed what might be considered a fair value from Woehler's experiments. All the parts (cylinders) exterior to the tube act within a range that even in the cylinder next the tube seldom equals the simple limit expressed by the symbol θ. That present practices are not dangerous seems to be amply proved by the endurance of hooped guns. I believe there has occurred no instance of the bursting (splitting) of a steel-hooped gun through the reinforce.

Assuming a "range of elasticity" for the gun steel to have been determined experimentally, no fundamental changes of formulæ need follow. There would at most be a change in the value of physical constants for the tube. In certain cases there would follow a restricted value of P_0, but in the majority of cases the theoretical value of P_0 as now deduced would not be lowered. And there would, in any case, still remain the superiority claimed over others for the built-up steel gun.

[a] Value given line 8, p. 100, corresponding to P=38,910.

The several quotations made by Mr. Haskell from the paper under discussion warrant the belief that the intention of the lecturer to give an account of the best performances and most favorable results from the past trials of the multicharge system has been appreciated. A statement now elicited is that the 6-inch gun tested at Sandy Hook, in 1884, represented the outcome of the labor of thirty years, and the expenditure of $300,000 in experiment and construction. Under these circumstances the presentation of the plea that the gun was made of weak material lays all the burden of the argument upon its advocates. The reasonable supposition is that the question of strength in this system was considered a matter of secondary importance. However that may be, the argument I have made that the question of strength in this gun is of primary importance loses none of its force. The 6-inch gun failed after a comparatively few rounds. As regards the question of strength, the gun therefore remains in the category of systems that have been tried and have failed. Relatively low pressures in this gun form no criterion for comparison of its strength with single-charged guns. Whether cast solid or built-up, or by whatever method this gun be constructed, the irregularities of form and the attachment of the pockets, for which the tube must be cut through in several places, present numerous sources of weakness.

The ballistic effect realized from the 6-inch multicharge gun would be a more pertinent subject for discussion if the strength of the system had been established. In discussing this question at any time, however, a rational method embracing all its bearings should be adopted. Fair comparisons do not consist in selecting one element out of many, as Mr. Haskell does. But even on his own ground: The 6-inch Armstrong ribband-gun, weight 3 tons, and the 6.3-inch Spanish gun, weight six tons, had each, at a prior date, given a higher muzzle energy than the best record of the 6-inch multicharge weighing 25 tons. The range of two guns at low angles of elevation affords no measure of their comparative power. All sorts of absurd deductions would follow from such a premise, e. g., the comparison which Mr. Haskell attempts to make between the 6-inch multicharge and the heavy caliber Krupp gun. In this case, moreover, taking the 111-pound shot with which the stated range of the multicharge gun was obtained, the comparative ability of this and the Krupp projectile to overcome the resistance of the air, is largely in favor of the Krupp. An approximately fair comparison could be made in this way in case the maximum range alone, to be obtained with each gun, were considered. Taking the case of two projectiles fired from the same gun, one of light weight and the other heavy, and the muzzle energies of the two supposed about equal: The light shot would give the greater range at small angles of elevation, while the heavy shot, owing to its greater sectional density, would give the greater maximum range, and also greater penetration and effect at any given range. When a projectile strikes a target which it can not penetrate, it is brought to rest by the resistance of the target, and the whole of the stored-up work in the projectile is exerted to overcome the target. In its flight through the air, as in firing for range, the resistance of that medium acts as a retarding force only, and the effective work of the projectile is principally used up by the resistance of the earth on striking. It is apparent, therefore, that the thickness of the wall of air (i. e., the range) through which a projectile passes does not afford a comparative measure of either the penetration or striking energy of the projectile on reaching a compact resistant material which absorbs the momentum of the projectile within a path limited to a few feet or less in length. The proper measure of effect can only be based upon the remaining energy at any given distance.

Captain Michaelis appears to have been led into error in comparing the features of construction in the Krupp gun with our present designs. The two

are in the main similar. In the latter the jacket constitutes the block-carrying cylinder, and performs the same functions as the corresponding piece in the Krupp gun. In neither case is the closure seated in the tube, which is thus relieved from the longitudinal strain due to the pressure on the breechblock. In reply to Captain Michaelis' remarks upon the success of cast guns in Sweden, I will refer to Commander Barber's remarks upon the same subject, which are published with this discussion.

Captain Butler presents, in a new and interesting light, the authorship of the designs of certain guns which he names. Ungenerous treatment on my part toward himself can evidently not be substantiated, since he has here, for the first time, so far as I know, divulged the nature and extent of a private and confidential compact made with Mr. Hunt. He states that Mr. Hunt is indebted to him for the designs of these guns. I am the more pleased to be able to call attention to this because, in claiming credit for work done by officers of the Ordnance Department, Captain Butler can by no means be left out. His careful and able work in the improvement of methods for attaching expanding sabots to the base of the muzzle-loading projectile has alone given him a wide reputation.

A letter dated Washington, March 3, 1887, signed Wm. P. Hunt, President South Boston Iron Works, was published in the National Republican of March 4, 1887. I take from that letter the following extract:

"In short the Getty Board gave me credit over all others for my design for a steel breech-loading rifle, and recommended that a 10-inch steel rifle be made after my design. With this diploma, I ventured to present my design for a cast-iron 12-inch Rodman rifle to the Select Committee on Ordnance, of which General Logan was chairman, and offered to make such a rifle at my own cost and subject to a firing test of 100 rounds, with charges of 150 pounds of powder and a 700-pound shot, and produce a muzzle energy of 10,000-foot tons. * * * I then entered a contract for five heavy guns, as follows:

'One 12-inch breech-loading Rodman rifle, entirely of cast iron.'

* * * * * * *

"These guns were all designed by the Ordnance Office. I found that my design, as given to the Logan Committee, had been increased in weight from 45 to 54 tons. This extra weight was placed mostly at the breech. Although the entire length has been increased 2 calibers, the thickness of wall at the muzzle was left the same. I found that my design, which provided for 150-pound charge, was changed so as to provide for 265-pound charge." * * *

From the information Captain Butler now gives, we learn that Mr. Hunt only spoke of "my design" in the sense that these designs were the property of the South Boston Iron Works. It is gratifying to know that the credit for them attaches to an officer of the Ordnance Department. It leaves the South Boston Iron Works with the credit of having made an excellent casting for this 12-inch rifle—which all will freely admit. Mr. Hunt gives the credit for the design of this gun as actually made to the Ordnance Office, and in this respect is more generous than Captain Butler, yet I may not do other than admit that had the latter been on duty in the Ordnance Office in place of the officers[a] who were there at the time, he might have contributed equally well to the result accomplished.

It may not be denied that enormous pressures recorded in the trials of cast-iron rifles, which are inconceivable when regarded as a register of the true *pres-*

[a] The writer was "employed elsewhere" at that time, and took no part in the alterations and improvements made in Mr. Hunt's, or rather Captain Butler's, design of the gun in question.

sure in the bore, have been repeatedly used as an argument in their favor. In the table given, page 126, Getty Board, the compilation of which it appears is due to Captain Butler himself, there is a selected record of twenty-seven pressures, of which eleven exceed 98,000 pounds, and no doubt is thrown by the compiler upon the authenticity of two records of 150,000 pounds, two of 200,000 pounds, and one of 240,000 pounds. Is it not reasonable to suppose that the pressure-gauges were more truthful in their record on June 14, 1870, when the following results were obtained? Seven rounds were fired on that day from 8-inch rifle No. 2, rounds numbered 836 to 842, inclusive; the charge throughout was 15 pounds of powder with Dyer solid shot of 150 pounds weight, and the pressures were, respectively, 21,000, 30,000, 23,000, 25,000, 18,000, 25,000, 28,000.

Individual opinion is, I suppose, always open to the charge of being influenced by prejudice. However, if the facts of a given case are substantiated, the public may judge for itself, and, noting that Captain Butler has not refuted any of the facts upon which were based my unfavorable conclusions upon the merits of cast-iron rifles, I am satisfied to let the opinions stand for what they are worth. The principal causes which led to the cessation of the manufacture of cast-iron rifles in this country were the findings of the Select Committee on Ordnance, 1869, and the unfavorable results of the trials of guns which I have authentically given, and no defense is needed for stating these plain facts of history.

In conclusion I will express my thanks for the kind appreciation of the gentlemen who have taken part in this discussion, and, at the same time, my regrets that I have been unable to discuss more fully the arguments made for and against the views presented in the lecture.

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